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GEOGRAPHIC DISTRIBUTION OF RARE PLANTS ON PUBLIC LANDS WITHIN THE RED MOUNTAIN STUDY AREA AND A STUDY OF THE POPULATION DYNAMICS AND REPRODUCTIVE BIOLOGY OF MCDONALD'S ROCK-CRESS, *Arabis mcdonaldiana* EASTWOOD

by

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for

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Final Report

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Michael F. Baad, Ph.D.

Geographic distribution of rare plants on public lands within the Red Mountain Study Area and a study of the population dynamics and reproductive biology of McDonald's rock-cress, *Arabis mcdonaldiana* Eastwood.

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Abstract

The geographic distributions of Arabis mcdonaldiana, Eriogonum kelloggii, Sedum laxum ssp. eastwoodiae and Silene campanulata were mapped and a total of thirty-seven new localities were recorded for these taxa in the vicinity of Red Mountain. In addition, a more indepth study of the population dynamics of Arabis mcdonaldiana was undertaken, with a series of thirty 5 square meter permanent plots located at random within the Red Mountain Study Area. Arabis was observed to maintain relatively stable mean population densities and canopy coverage values over the three years of the study, and artificial crossing and bagging experiments determined it to be a self compatible facultative outcrosser, with two species of bumble bee (Bombus caliginosus and B. edwardsii) the principal pollinating agents. Although silique predation by rodents and other animals may be periodically significant, Arabis' relatively long-life appears to buffer the species against short term lapses in reproductive effectiveness. All observations indicate that Arabis mcdonaldiana is restricted to Huse Soils and appears to share habitat requirements with Eriogonum kelloggii and Ceanothus pumilus. The continued survival of Arabis mcdonaldiana, as well as that of the other three species of geographically restricted plants requires the reclassification of the Red Mountain Area as critical habitat essential for the long term maintenance of these species populations.

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Introduction

Negotiated Solicitation No. YA551-RFP4-340009 provided for a study of the geographic distribution of rare plants on Red Mountain and adjacent federal lands as well as a study of the population dynamics and life cycle of one of these endemic taxa, Arabis mcdonaldiana Eastwood, a species currently listed as endangered by both the U.S. government and the State of California. Recently, existing plans of mining interests to develop and exploit the mineral resources on Red Mountain have stimulated interest in the ecology of McDonald's Rock-cress as well as the other sensitive plant species similarly restricted in their distribution to Red Mountain. Specifically, the Recovery Plan for McDonald's Rock-cress (U.S. Fish and Wildlife Service 1984) stipulates that in order to protect the rock-cress population from mining and other deleterious impacts, essential habitat must be identified and research conducted on the species' life history requirements in order to determine criteria for its eventual delisting as an endangered species. In accordance with the Recovery plan, a three year study of this species was initiated in 1984 designed to estimate the following population parameters:

1) The geographic distribution of Arabis mcdonaldiana as well as those of Eriogonum kelloggii, Sedum laxum ssp. eastwoodiae, and Silene campanulata ssp. campanulata on public lands within the Red Mountain Study Area.
2) Spatial and temporal variations in Arabis population density observed over a three year period.
3) A description of the essential life history stages of Arabis and an analysis of stage specific limiting factors critical to the survival of the species.

4) A determination of the species' habitat requirements.

Based upon these data, specific habitat management recommendations were developed and designed to insure the continued survival of McDonald's Rock-cress on Red Mountain. The following is a draft final report of this study.

The geology and vegetation of Red Mountain have been described elsewhere (U.S. Fish and Wildlife Service 1984; Goforth 1982; Knight, W. and Knight, I. 1971) and the taxonomy of Arabis mcdonaldiana has been summarized by Rollins (1973). The taxonomic uniqueness of the Red Mountain Arabis populations as compared with recently discovered populations in Del Norte County, California, and adjacent Curry County, Oregon, is a subject of much interest to those concerned with managing federal lands and interpreting laws designed to protect sensitive plant species. However, the focus of this study was more narrowly ecological and will likely be of only marginal assistance to those concerned with unravelling the problems of divergence and putative reproductive isolation existing between populations of purple-flowered Arabis.

The Geographic Distribution of Sensitive Taxa on Red Mountain

An essential first step prior to developing a management plan for the Red Mountain Study Area is the accurate mapping of the ranges of sensitive taxa within this region. During the three years of this study, federally administered lands within the Red Mountain Study Area including Little Red Mountain to the west were systematically traversed on foot using transects spaced at 100 foot intervals to determine the locations of previously unrecorded populations of the four sensitive taxa. Localities described by earlier workers were revisited as well, and the geographic position of each population was recorded on U.S.G.S. 7-1/2 minute topographic maps. Thirty-

seven previously unmapped populations of sensitive taxa were added to the original twenty-five known localities within the Study Area (see Figures 1-4 for the locations of these populations). Although several previously undocumented populations of each taxon were found, the total ranges of these four taxa on the mountain remain archipelagoes of disjunct clusters of individuals separated by relatively broad intervening stretches of seemingly occupiable habitat.

Although the main thrust of this project was a study of Arabis mcdonaldiana, an examination of the range maps reveals that Silene campanulata ssp. campanulata and Sedum laxum ssp. eastwoodiae are considerably more restricted in their distributions and are known from far fewer populations than the target species of this study. During the section of this report dealing with specific habitat management recommendations these points will be more thoroughly discussed.

Spatial and Temporal Variations in the Density and Coverage of Arabis mcdonaldiana on Red Mountain

Estimations of changes in population density over time

As each population of Arabis was located, it was mapped and assigned a number, and a rough count of all individuals/population was made. Initially a total count of individuals of all ages was attempted, but it soon became apparent that most populations, in addition to reproductive individuals, were represented by large cohorts of immature and/or nonflowering plants which were too numerous to count. Temporarily ignoring nonreproductive individuals, a total census of fruiting individuals was conducted, and these primary population density estimates were used to plan a distribution of permanent sample plots so that the resulting survey would proportionately reflect the

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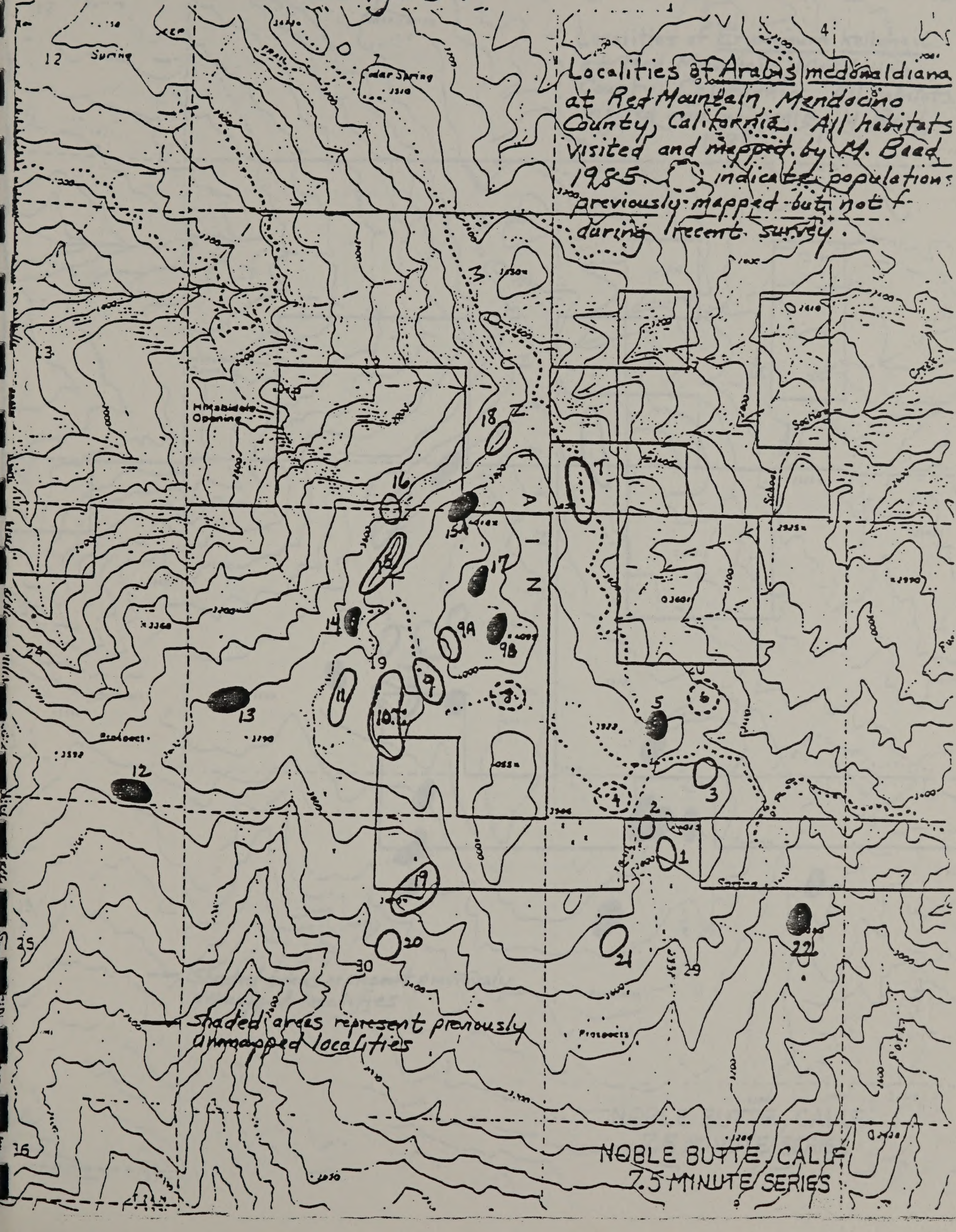
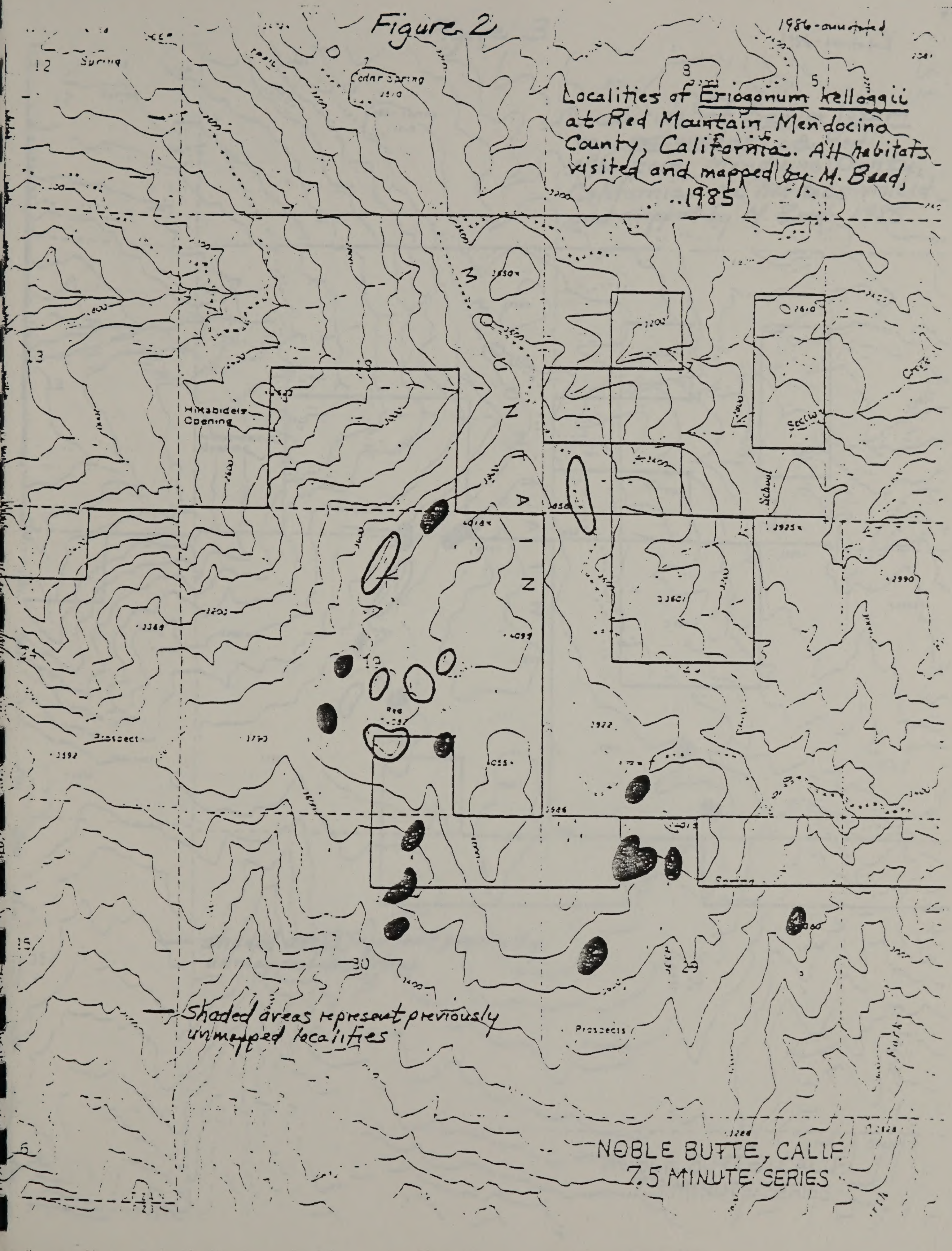
Figure 1



Localities of *Arabis mcdonaldiana* at Red Mountain, Mendocino County, California. All habitats visited and mapped by M. Bead 1985. ◌ indicate populations previously mapped but not f during recent survey.

Shaded areas represent previously unmapped localities

Figure 2



1986-annotated

Localities of *Eriogonum kelloggii* at Red Mountain Mendocino County, California. ~~All~~ habitats visited and mapped by M. Bead, 1985

Shaded areas represent previously unmapped localities

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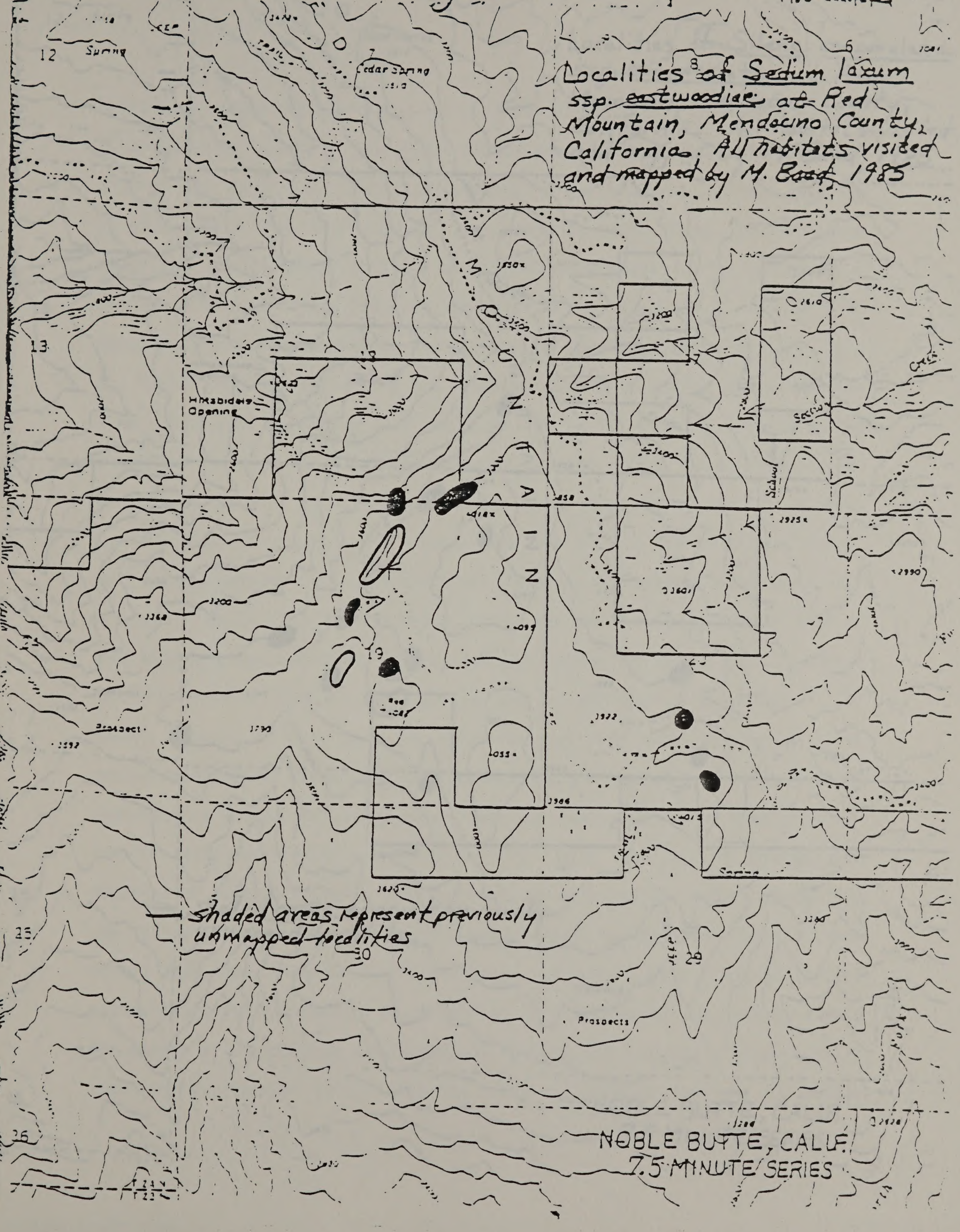
Figure 3



1986-annotated

Localities of *Sedum laxum* ssp. *eastwoodiae* at Red Mountain, Mendocino County, California. All habitats visited and mapped by M. Boad 1985

shaded areas represent previously unmapped localities

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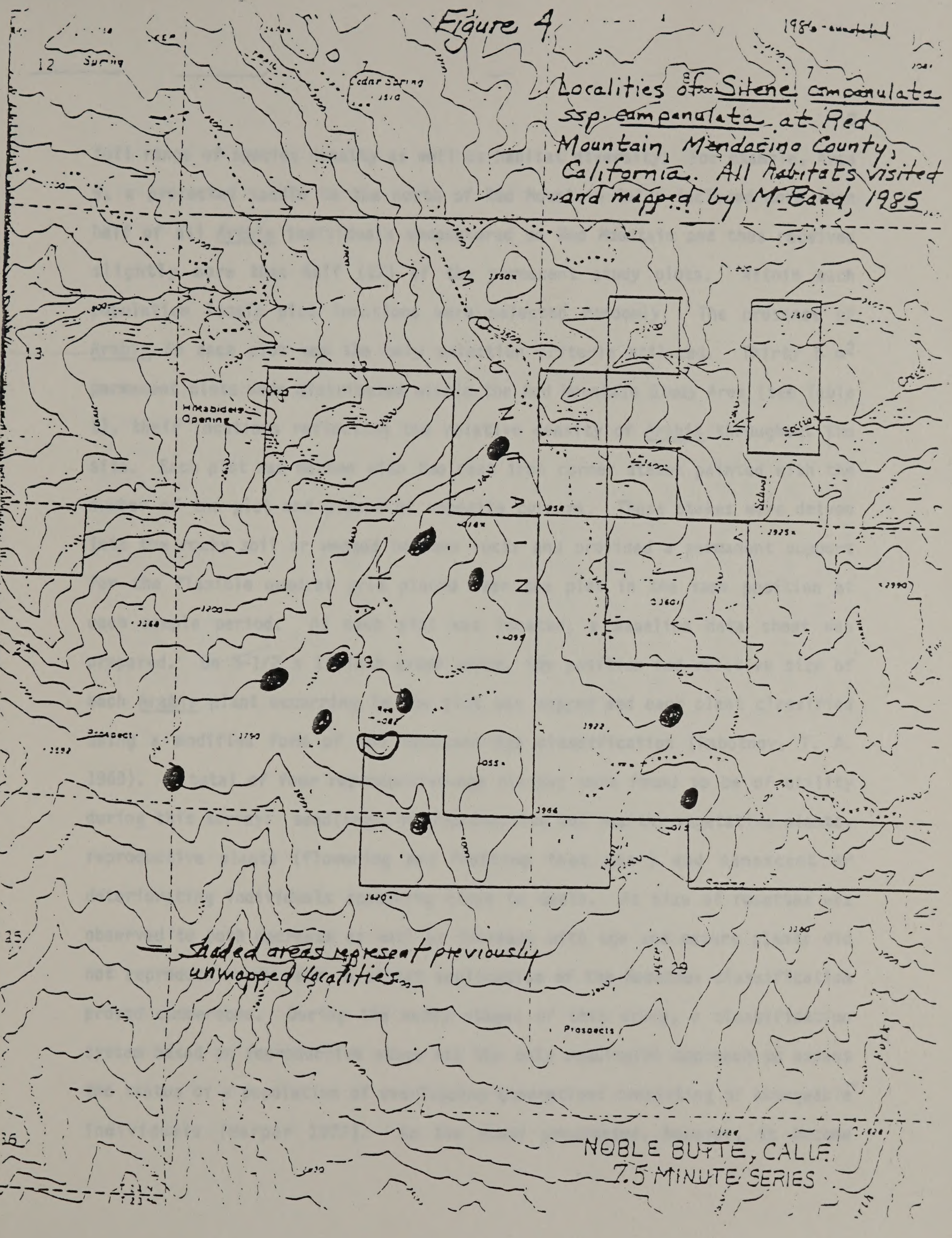
Figure 4

1986-annotated



Localities of Silene campanulata ssp. campanulata at Red Mountain, Mendocino County, California. All habitats visited and mapped by M. Baad, 1985

— Shaded areas represent previously unmapped localities

full range of species density as well as habitat diversity. For example, Area 9, a protected saddle to the north of Red Mountain Baldy included more than half of all Arabis individuals encountered on Red Mountain and thus received slightly more than half (17) of the permanent study plots. Within each population locale plot locations were selected randomly. The presence of Arabis in each plot was the only selection criteria utilized. Thirty 5 m^2 permanent plots were distributed within the Red Mountain Study Area (see Table 1), their locations reflecting the relative density of Arabis throughout the site. Each plot was marked with two cast iron corner stakes painted with the number of the plot and placed at opposite corners. These stakes were driven into the rocky soil or wedged between rocks and provided a permanent support for the flexible quadrat grid placed over the plot in the same position at each sample period. As each plot was located, a baseline data sheet was prepared. On 8-1/2 x 11 inch graph paper, the position and relative size of each Arabis plant occurring in the plot was mapped and each plant classified using a modified form of the Rabotnov Age classification (Rabotnov, T. A. 1969). A total of four reproductive-age classes were found to be of utility during this survey: seedlings, nonreproductive but healthy vegetative plants, reproductive plants (flowering and fruiting that year) and senescent or deteriorating individuals appearing close to death. As size of rosettes was observed to both decrease as well as increase with age and mature plants did not reproduce every year, a strict application of the Rabotnov classification proved cumbersome. During the early stages of this study, a classification system based on reproductive stage was the only meaningful approach to assess the status of a population of overlapping generations consisting of nonageable individuals (Harper 1977). As the study progressed, however, it became

possible to monitor seedlings' beginning growth at a particular period and at that point in time more accurate population age structure data began to emerge.

Table 1

Locations of Thirty-Five Square Meter Permanent
Plots Containing Arabis mcdonaldiana*

Plot Numbers	Study Area	Study Area Location
Plots 1-17	Area 9	NW¼SE¼, Sec. 19, T. 24 N., R. 16 W.
Plot 18	Area 9A	SW¼NE¼, Sec. 19, T. 24 N., R. 16 W.
Plots 19-23	Area 15	NW¼NE¼, Sec. 19, T. 24 N., R. 16 W.
Plot 24	Area 15A	SW¼SE¼, Sec. 18, T. 24 N., R. 16 W.
Plot 25	Area 11	NE¼SW¼, Sec. 19, T. 24 N., R. 16 W.
Plot 26-30	Area 10	NW¼SE¼, Sec. 19, T. 24 N., R. 16 W.

* see Figure 9 for Map of Study Area Locations

In addition to _Arabis_, the location and relative sizes of associated plant species occurring on the plots were also mapped so that inter- as well as intraspecific interactions could be observed over time. Although time constraints allowed for only a single set of observations to be obtained from the permanent plots during the first field season (1984), two sets of data were collected annually in 1985 and 1986 for a total of five complete sets of data gathered from the 30 permanent plots (data collection dates were June 4 and July 20 each year). Data collection periods were spaced to reflect in June: seed germination success following winter and spring rains and the end

of anthesis and fruit set, and in July: the relative success of fruit maturation and the survival of new seedlings following the first months of warm summer weather.

One direct benefit from the permanent plot data is that they yield a stratified random estimate of Arabis population density at six different locations within the Red Mountain Study Area. Each of these six localities share an exposure to full sun and a relatively low density of plant biomass. At one site (Area 9), the zone of highest Arabis density (Figure 9), the habitat, although still relatively open, is closing rapidly as shrubs and trees invade a previous burn site. The remaining sample sites appear to be more or less permanently barren of vegetation due to unstable soil conditions or exposed bedrock.

Figures 5-8 depict the average population density of Arabis mcdonaldiana observed on the six areas during the three consecutive midsummer sampling periods. The total height of each bar graph is proportionate to the Arabis density at each site and time period. Each bar has been dissected and offset to reflect the mean numbers of individuals belonging to each of the four reproductive classes.

Over the three year period of this study, it became apparent that plants growing in Area 9, a protected valley and the site of a past burn (40-50 years ago as indicated by the ages of larger knobcone pine at this location) are maintaining a mean population density two to three times higher than at the remaining five areas sampled. The reproductive and nonreproductive age classes together are increasing in total numbers and, as individuals may move back and forth between these two categories over time, these groups of plants are best considered together when viewing the pattern of changing density in a

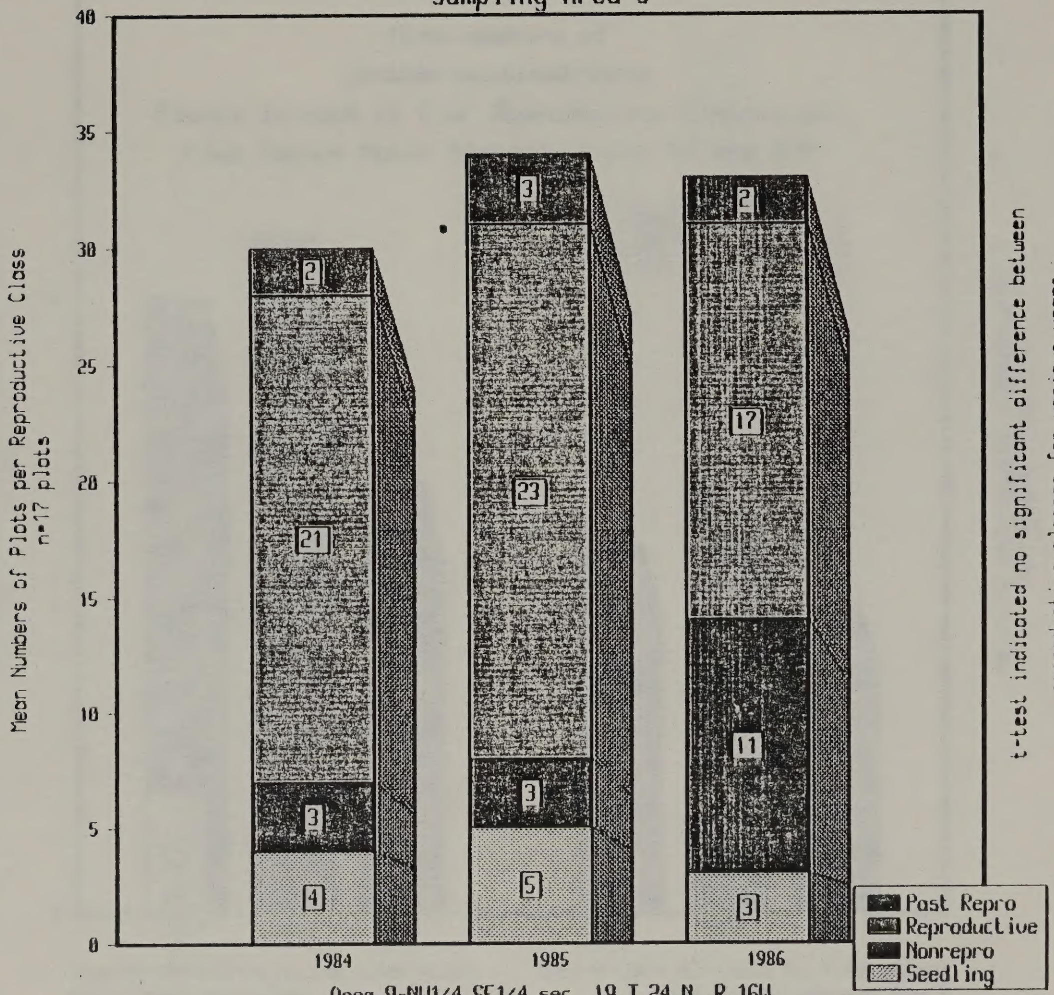
Figure 5

Mean Numbers of

Arabis mcdonaldiana

Plants in Each of Four Reproductive Classes per 5m Plot

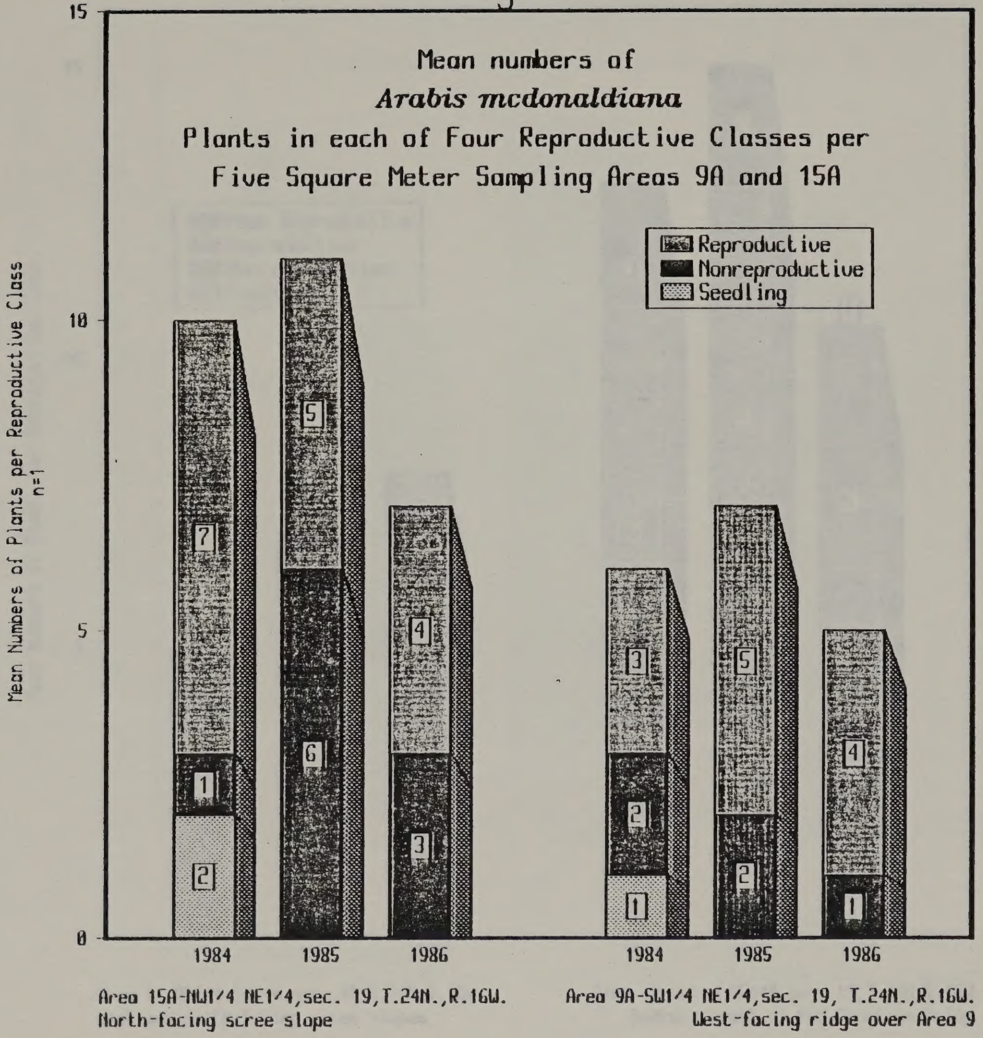
Sampling Area 9



t-test indicated no significant difference between reproductive classes for various years

Area 9-NW1/4 SE1/4,sec. 19,T.24 N.,R.16W.
protected valley straddling road
site of past burn

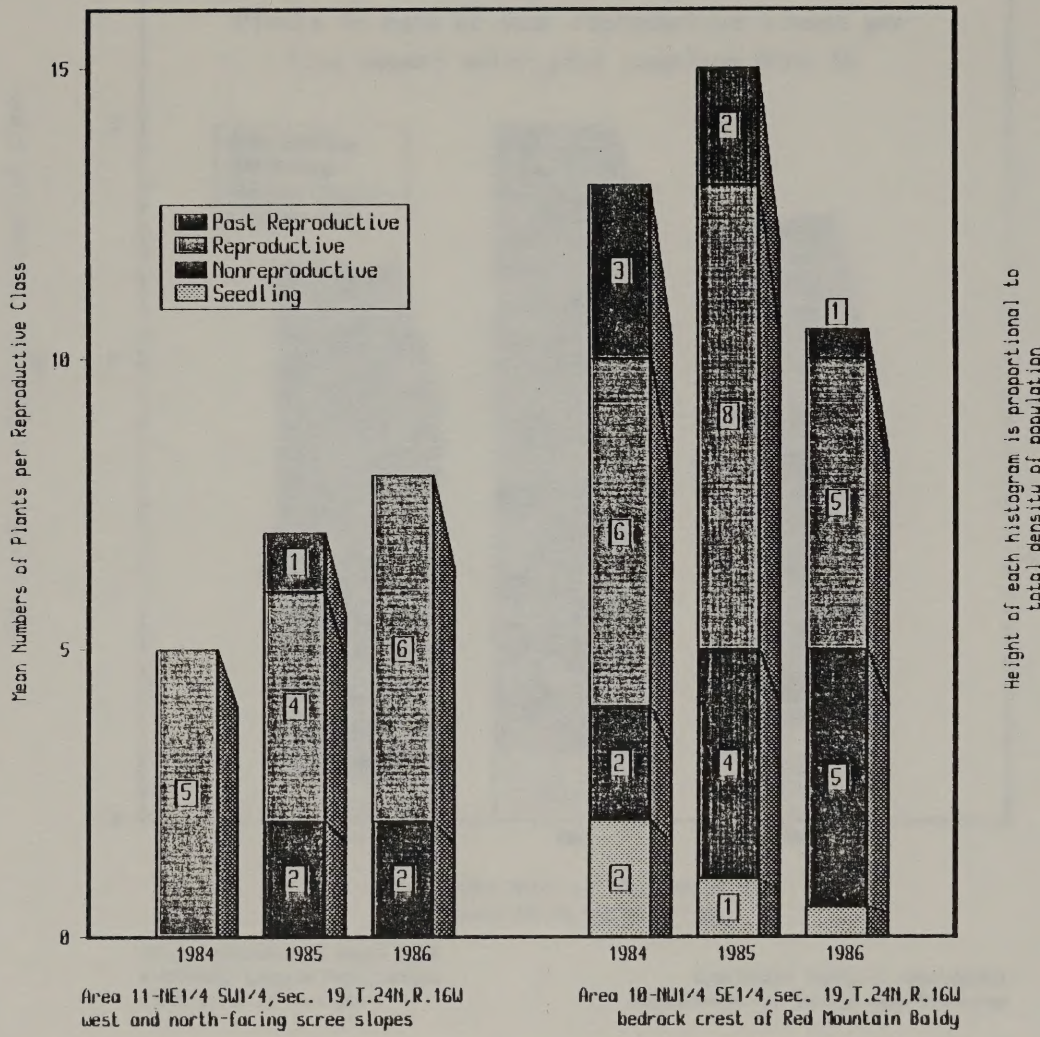
Figure 6



Height of each histogram is proportional to
total density of population.

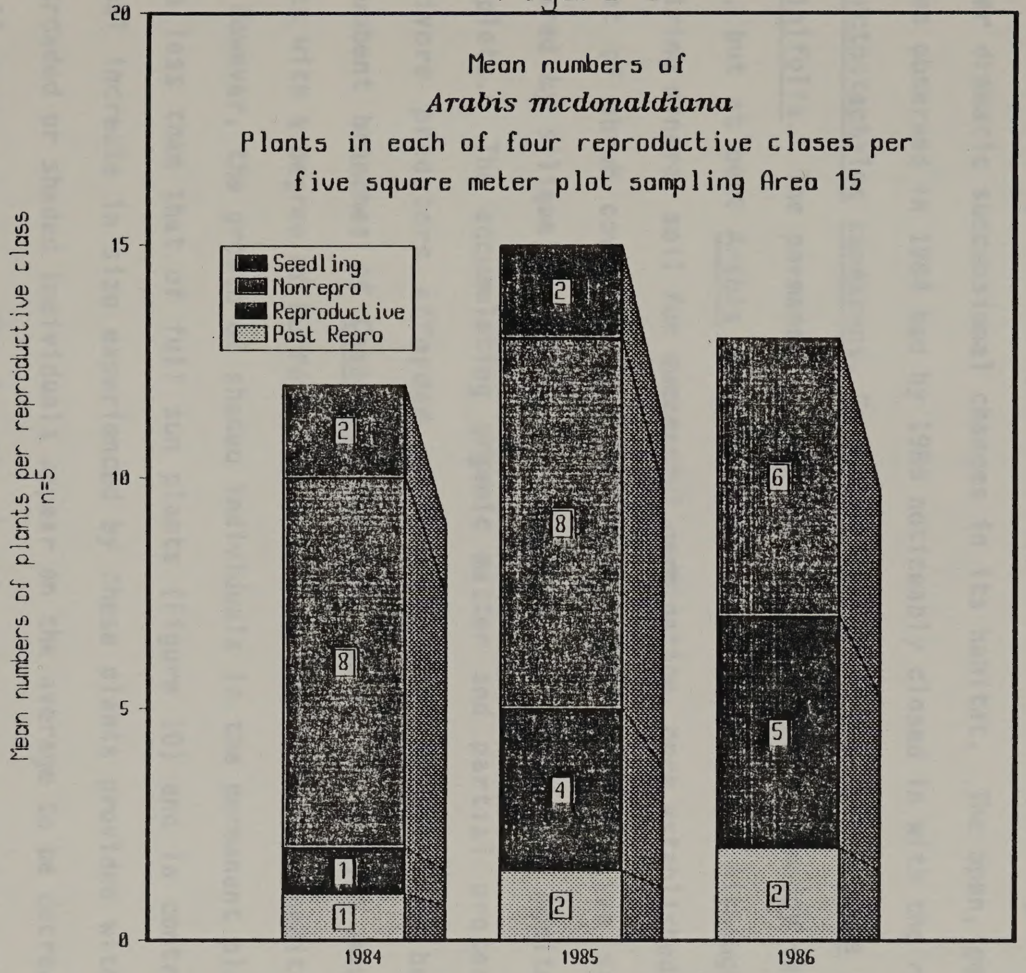
Figure 7

Mean numbers of
Arabis mcdonaldiana
Plants in each of Four Reproductive Classes per
five square meter plot sampling areas 10 and 11



Height of each histogram is proportional to total density of population

Figure 8



Mean numbers of

Arabis mcdonaldiana

Plants in each of four reproductive clases per five square meter plot sampling Area 15

Area 15-NW1/4 NE1/4,sec. 19,T.24N.,R.16W
Northwest-facing hog back ridge

T-test indicated no significant
difference between reproductive
classes for various years

Confidence limits of mean(α=.05)
indicated to the left of each histogram

Height of each histogram is proportional to
total density of population

particular population. Area 9 plants have also been relatively more successful in producing new seedlings each of the three years of the study, and these facts considered together indicate relatively healthy prospects for the Area 9 population--at least in the short term. This population remains, however, something of an enigma as it appears to be flourishing in the face of rather dramatic successional changes in its habitat. The open, gentle, rocky slopes observed in 1984 had by 1986 noticeably closed in with the rapid growth of Arctostaphylos canescens, Ceanothus pumilus, Pinus lambertiana and Quercus vaccinifolia. The permanent plots reflect this influx of woody vegetation as well, but at best Arabis appears to be holding its own. Although seemingly requiring mineral soil for successful germination, once established, a certain amount of shrub cover appears to increase the reproductive success (as measured by silique production) of those Arabis individuals monitored within the plots. The accumulating organic matter and partial protection from herbivore predators afforded by the shrubs, particularly between the procumbent branches of Ceanothus pumilus, appear to provide mature Arabis plants with a degree of buffering from extreme environmental conditions.

However, the growth of shaded individuals in the permanent plots appears to be less than that of full sun plants (Figure 10) and in contrast to the gradual increase in size experienced by these plants provided with full sun, the crowded or shaded individuals appear on the average to be decreasing their overall canopy cover. The length of this study has provided too few data points to define significant trends but the rate of growth particularly in 1986 appears to be decidedly lower within areas of increasing shrub cover. It remains to be seen, however, what long term success this population will have at Area 9. In the absence of fire, acting to reopen the site and remove

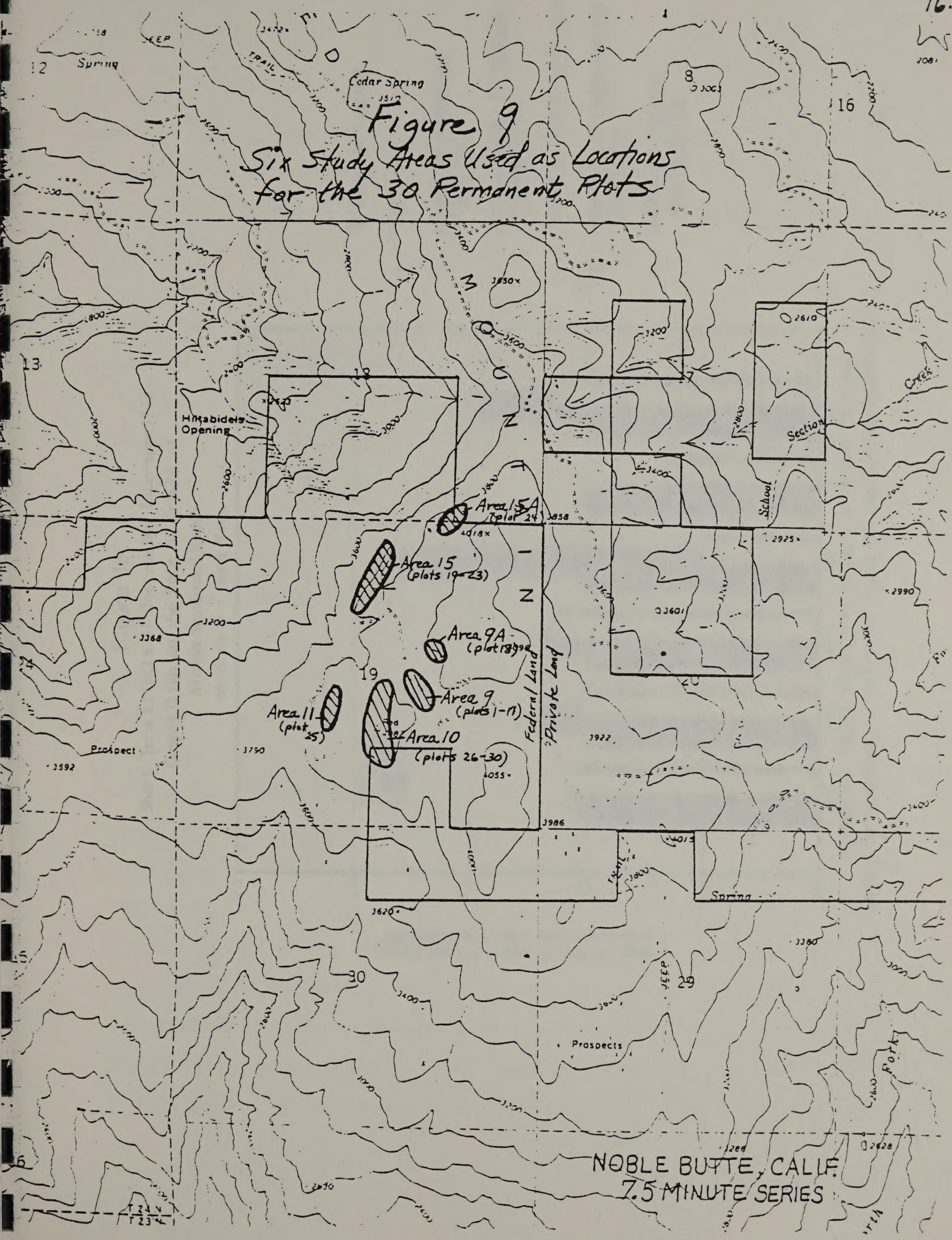
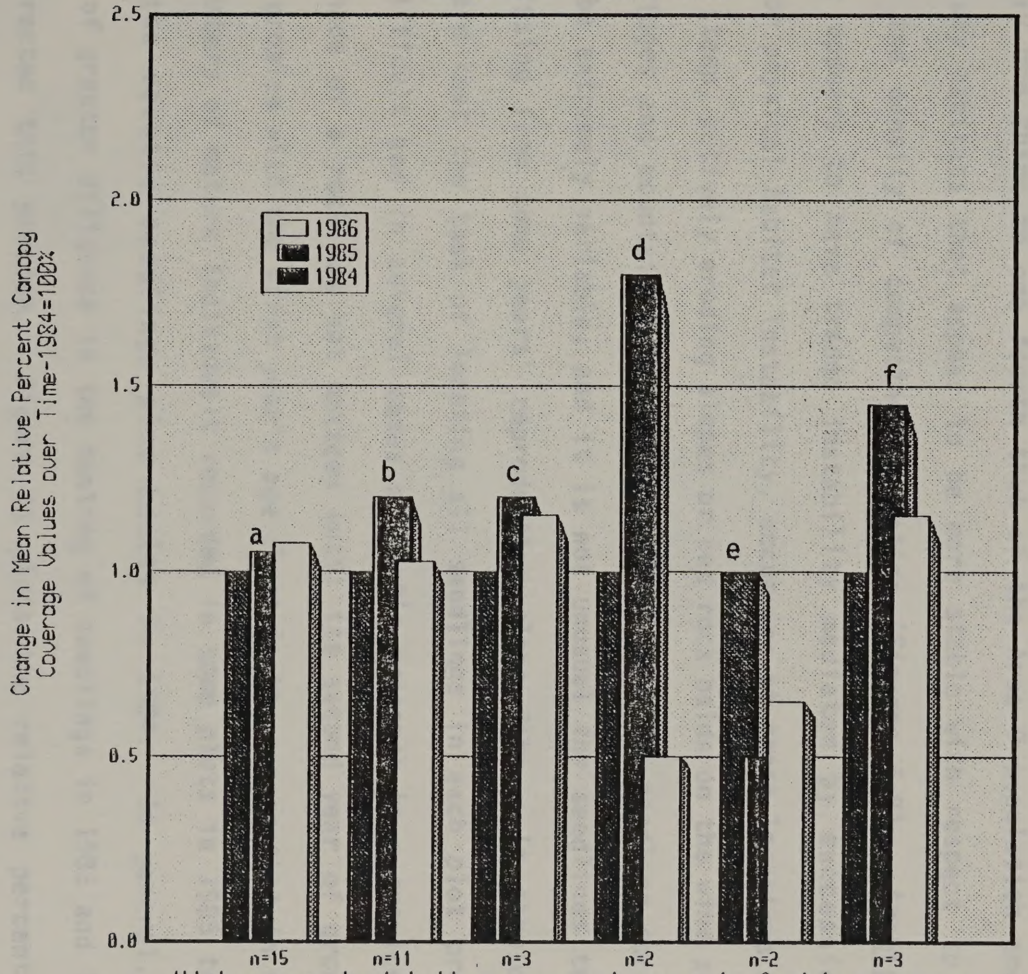


Figure 9
Six Study Areas Used as Locations for the 30 Permanent Plots

Figure 10

Short Term Effects of Increasing Interspecific Competition on the Rate of Growth of *Arabis mcdonaldiana* at Area 9 - Burn Site



Histograms depict three year changes in Arabis coverage values for a variety of different types of competitive interaction.

Histogram Legend

a - "full sun"

b - shaded by Ceanothus pumilus

c - surrounded by Eriogonum Kelloggii

d - shaded by Pinus attenuatus

e - shaded by Arctostaphylos canescens

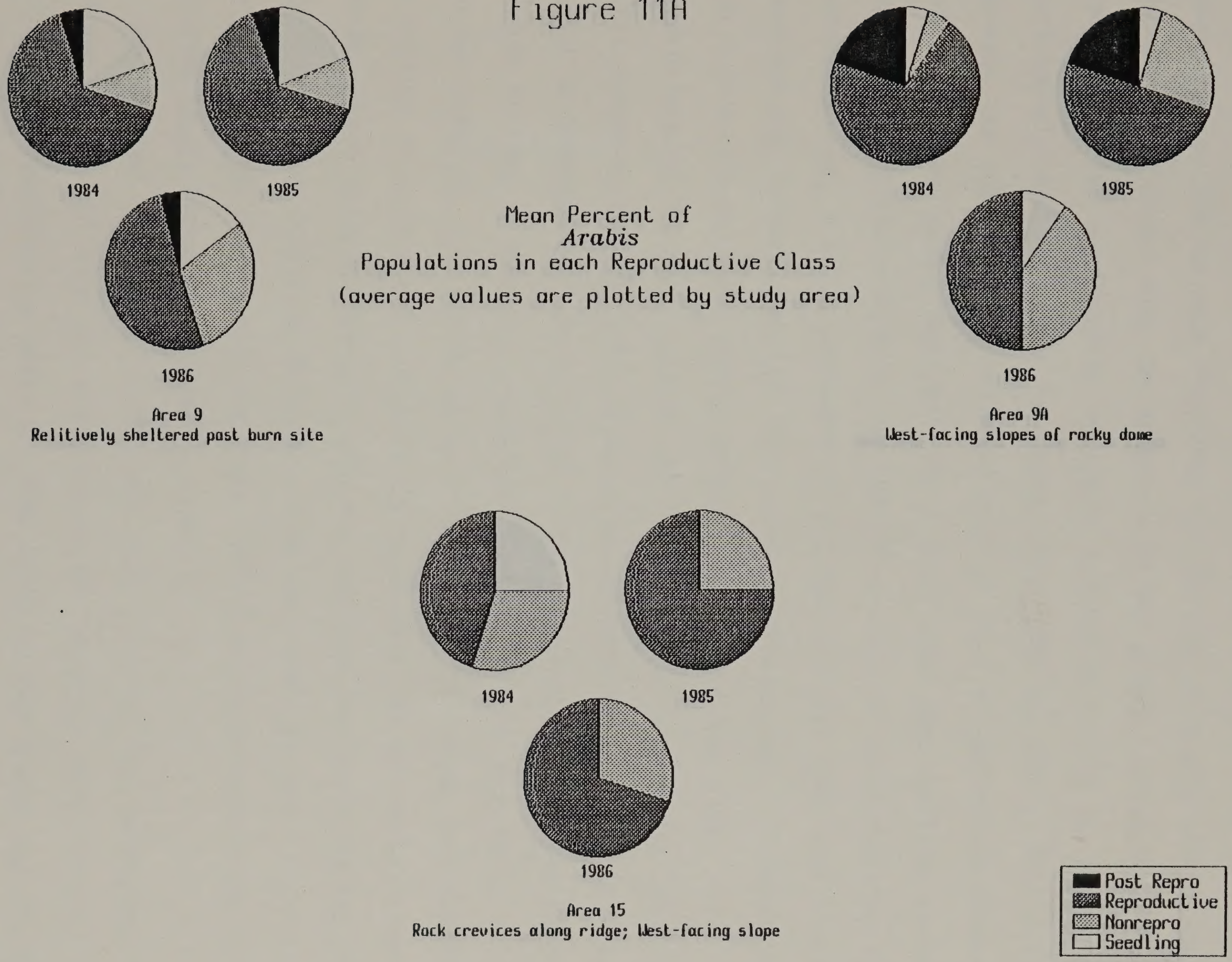
f - shaded by Quercus vaccinifolia

competing woody vegetation, Arabis' future here is problematic at best. A similar site located on private land at the northeastern end of Red Mountain (SW1/4 SW1/4 of sec. 17, T.24N., R.16W.) appears to have experienced a marked drop in density of Arabis during the period of this study.

The density of Arabis populations elsewhere on Red Mountain average approximately one third to one fourth that of the Area 9 population and in general occupy habitats that appear to be more stable with respect to the composition and density of competing vegetation (Figures 6-8). Arabis on these sites appears to have traded instability mediated by successional processes for physical habitat instability, occupying at these locations rock crevices on steep, actively eroding slopes or bed rock balds on the wind swept crests of ridges and mountain tops. Within these habitats seedling success appears to be extremely variable, and it is not unusual for seedlings to be entirely missing from some years' reproductive class data. It should be mentioned here that the task of locating all seedlings in each plot proved extremely difficult and in several cases a plant's presence in a crevice or under the shade of a rock was not noticed until its second year of growth. This census problem with the first year's age class is the reason that in some cases the numbers of mature individuals recorded in some plots in 1985 total more than the counted seedlings plus adults in 1984. In general, an application of greater diligence in the hunting of seedlings in 1985 and 1986 largely corrected this problem. Figure 11 plots the relative percent of Arabis in each reproductive class. Relative patterns of reproductive class distribution may then be compared more easily habitat by habitat. Areas 9A and 11 can be seen to have the least seedling establishment success proportionate to their overall densities. In contrast Areas 9, 10 and 15 were able

Figure 11A

Mean Percent of *Arabis* Populations in each Reproductive Class (average values are plotted by study area)



Area 9
Relitively sheltered past burn site

Area 9A
West-facing slopes of rocky dome

Area 15
Rock crevices along ridge; West-facing slope

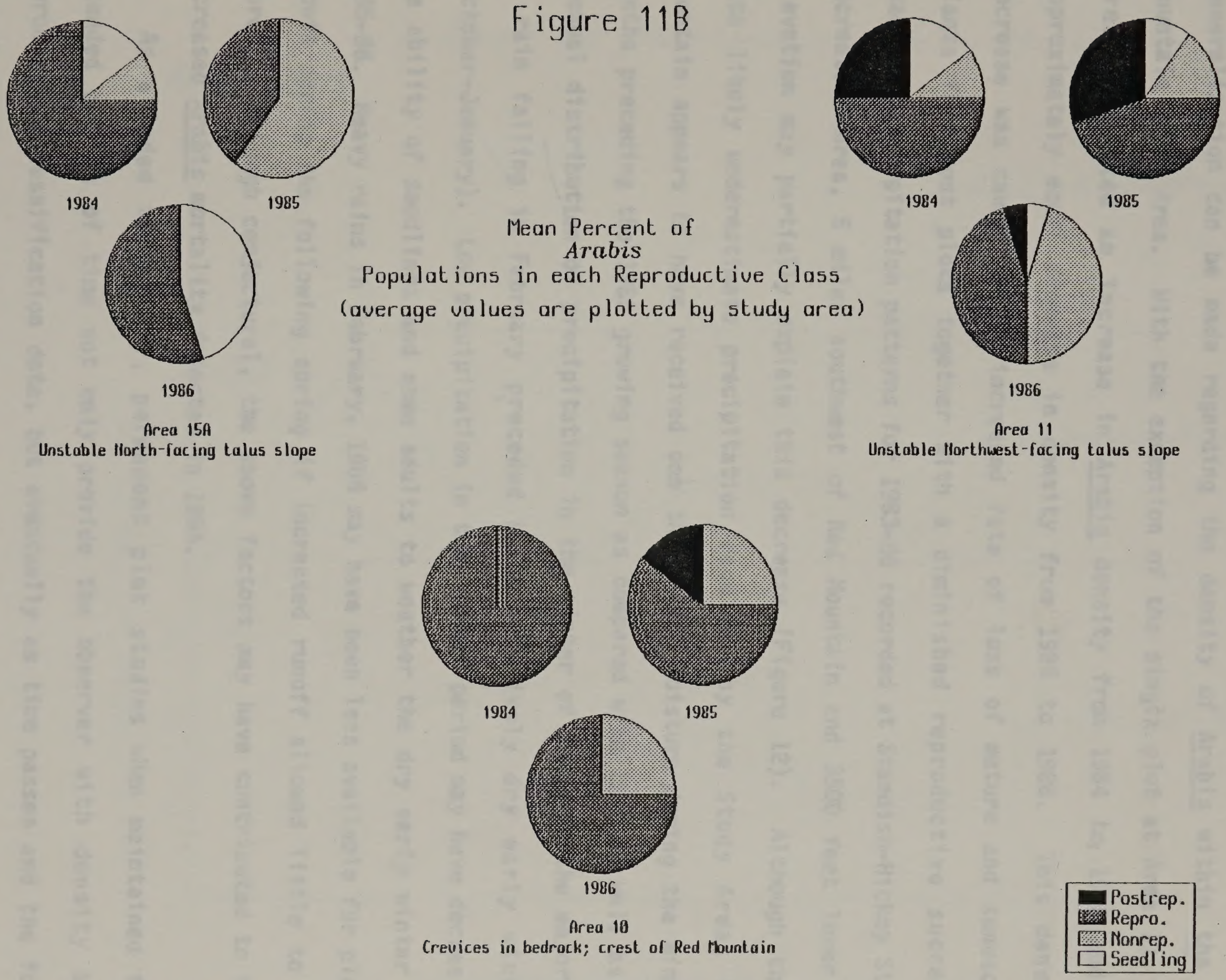


Figure 11B

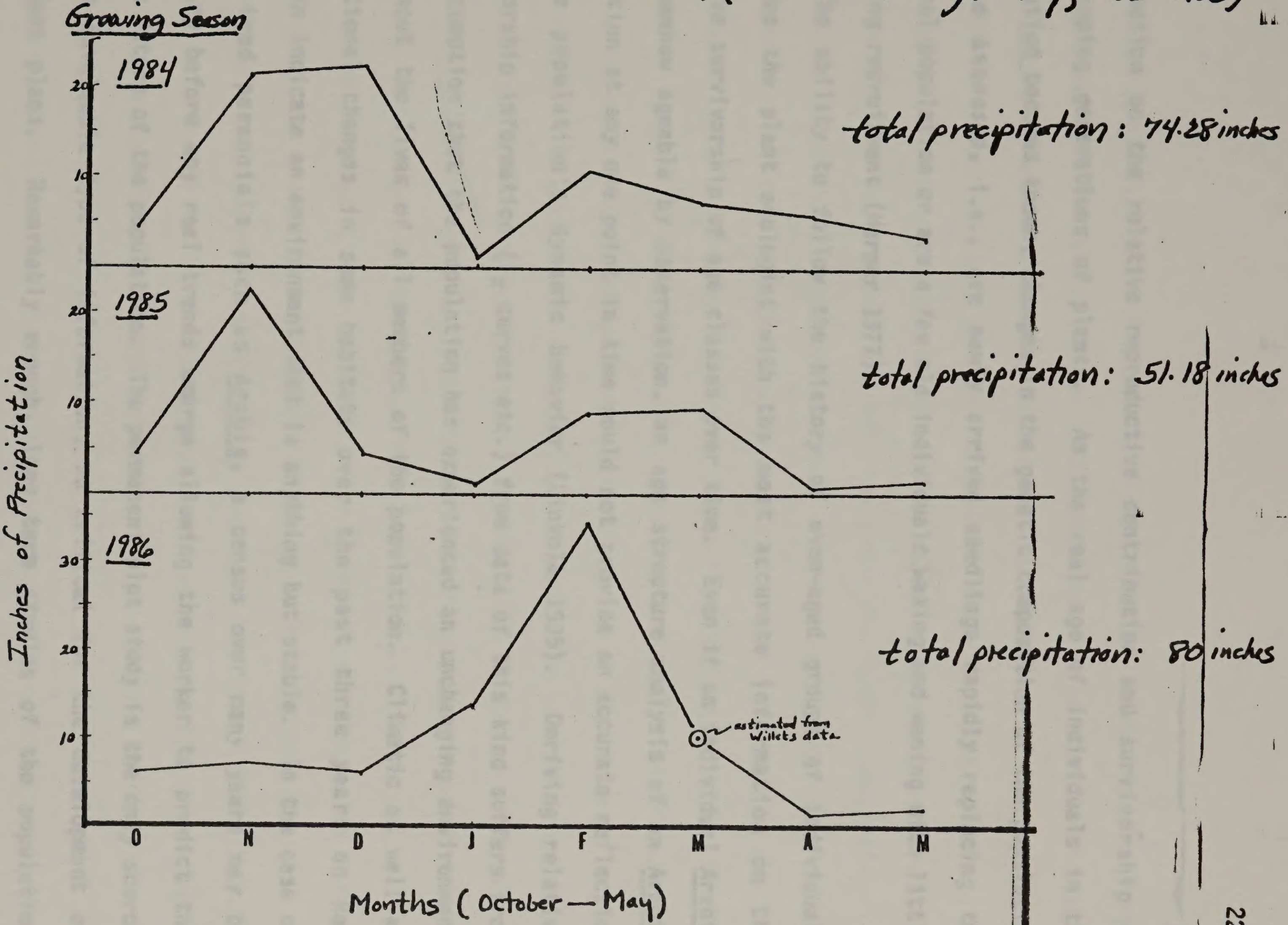
Mean Percent of *Arabis* Populations in each Reproductive Class (average values are plotted by study area)

to establish some seedlings each of the three years of the study. One overall generalization can be made regarding the density of Arabis within the Red Mountain Study Area. With the exception of the single plot at Area 11, all areas exhibited an increase in Arabis density from 1984 to 1985 and an approximately equal decrease in density from 1985 to 1986. This density decrease was caused by an increased rate of loss of mature and senescent plants from most plots together with a diminished reproductive success. Examining precipitation patterns for 1983-86 recorded at Standish-Hickey State Recreation Area, 5 miles southwest of Red Mountain and 3500 feet lower in elevation may partially explain this decrease (Figure 12). Although these data likely underestimate precipitation received by the Study Area, Red Mountain appears to have received one third less moisture during the winter months preceding the 1985 growing season as compared with 1984 as well as an unusual distribution of precipitation in the winter of 1985-86; the majority of rain falling in February preceded by a relatively dry early winter (October-January). Low precipitation in the 1984-85 period may have decreased the ability of seedlings and some adults to weather the dry early winter of 1985-86. Heavy rains in February, 1986 may have been less available for plant growth during the following spring if increased runoff allowed little to be stored. Although conjectural, the above factors may have contributed to the increased Arabis mortality detected in 1986.

As alluded to earlier, permanent plot studies when maintained for extended periods of time not only provide the observer with density and reproductive classification data, but eventually as time passes and the fate of each plant on the plot is recorded, the investigator is provided with an opportunity to follow even-aged cohorts of individuals through time and obtain

Figure 12

Monthly Precipitation Totals Recorded at Standish-Hickey State Recreation Area, Five Miles Southwest of Red Mountain (October through May, 1983-1986)



information on the relative reproductive contribution and survivorship of overlapping generations of plants. As the real age of individuals in the population becomes known, changes in the genetic composition of the population can be assessed, i.e., are newly arrived seedlings rapidly replacing the residual population or are a few old individuals waxing and waning with little seedling recruitment (Harper 1977).

The ability to follow the history of even-aged groups of individuals provides the plant ecologist with the most accurate information on the relative survivorship of age classes over time. Even if an individual Arabis was somehow ageable by observation, an age structure analysis of an Arabis population at any one point in time would not provide an accurate reflection of the population's dynamic behavior (Linkola 1935). Deriving relative survivorship information (l_x curves etc.) from data of this kind suffers from the assumption that the population has experienced an unchanging environment throughout the lives of all members of the population. Climatic as well as vegetational changes in some habitats over the past three years on Red Mountain indicate an environment that is anything but stable. In the case of long lived perennials such as Arabis, a census over many years may be necessary before any real trends emerge allowing the worker to predict the dynamic future of the population. The permanent plot study is the only source of this invaluable type of information, so critical for the development of management plans. Remarkably enough, long term studies of the population dynamics of herbaceous perennials (such as Arabis) are relatively scarce. The classic studies of C. O. Tamm (1948, 1956a, 1956b, 1972a, 1972b) monitoring herb populations in Swedish meadows and forests over the past 35 years are unique in their exhaustive detail and duration. Harper and his students'

studies of herbaceous plant interactions over time in Great Britain (Harper and Sazar 1953, Sarukhan and Harper 1973) have contributed much to our basic understanding of plant population dynamics. All studies to date, however, have been conducted on plant species that suffer their greatest mortality via interactions with other plants of the same or different species, intense intra and inter specific competition have been the principle factors responsible for shaping the population's age distribution. No published long term studies have been carried out on herbaceous perennials living in unstable physical environments such as the talus slopes of xeric windswept balds of Red Mountain. Placed in this perspective, the permanent plot studies on Red Mountain represent an opportunity to contribute in a unique way to our understanding of plant population dynamics. Three years of data are sparse, but Figure 13A and B represent arithmetic and log plots of the survivorship of the 1984 Arabis seedling crop exposed to three different environments: (1) a recovering burn (Area 9), (2) exposed crevices in bedrock (Area 10) and (3) steep, unstable, talus slopes (Area 15). The genetic constitution of each of these populations is likely different, although Goforth (1982) may wish to challenge this contention. Over time with permanent plot data, it is possible to trace the relative probability of survival of seedlings exposed to different environments. One could determine if the relative survivorship of seedlings experiencing competition for light and moisture in Area 9 was significantly different from that of Arabis populations in more exposed sites. When data from Area 9 are converted to log values, the three points suggest a straight line inferring a constant rate of death and no greater probability of loss as a first year plant than as a second year plant. A constant risk of death does not mean that equal numbers die each year from each age group but

rather that equal proportions are lost. Obviously as pointed out earlier, for long lived perennials such as Arabis, more years' data are needed to discern a significant trend.

Estimations of canopy coverage

In addition to allowing for the measurement of fluctuations in density, permanent plots also provide an opportunity to monitor changes in the canopy coverage of Arabis within and between sampling sites. Figure 14 shows the mean canopy coverage of Arabis in each of the six sample areas for each of the three years of the study.

In general, fluctuations in canopy cover reflect changes in the average size of Arabis plants as well as incremental increases or decreases in numbers of individuals per plot. Increases in canopy cover are indicative not only of increases in the number of genets (new genetically unique individuals), but also in the number of ramets (rosettes) genetically identical and potentially able to reproduce independently of the mother plant. As density counts largely census numbers of genets, the canopy cover values give a more complete impression of the changes in energy flow through the Arabis population. Fluctuations in reproductive success apparent from observing changes in the density data are not necessarily reflected in the coverage values. In fact no clear pattern of canopy coverage increase or decrease emerges when all sample areas are considered together. The single plot of Area 9A located on a bedrock bald above Area 9 showed a progressive increase in canopy coverage over time from 472 to 641 cm^2. At this site, growth is concentrated in only 5 plants. In contrast, Area 15 (5 plots), Area 15A (1 plot) and Area 10 (5 plots), all exposed ridge top localities with relatively low densities showed a gradual decrease in the canopy coverage per plot. At Area 9, the area

Figure 14

Fluctuations in Mean Canopy Coverage of *Arabis mcdonaldiana* Over a Three Year Period as Observed in Five Square Meter Permanent Plots.

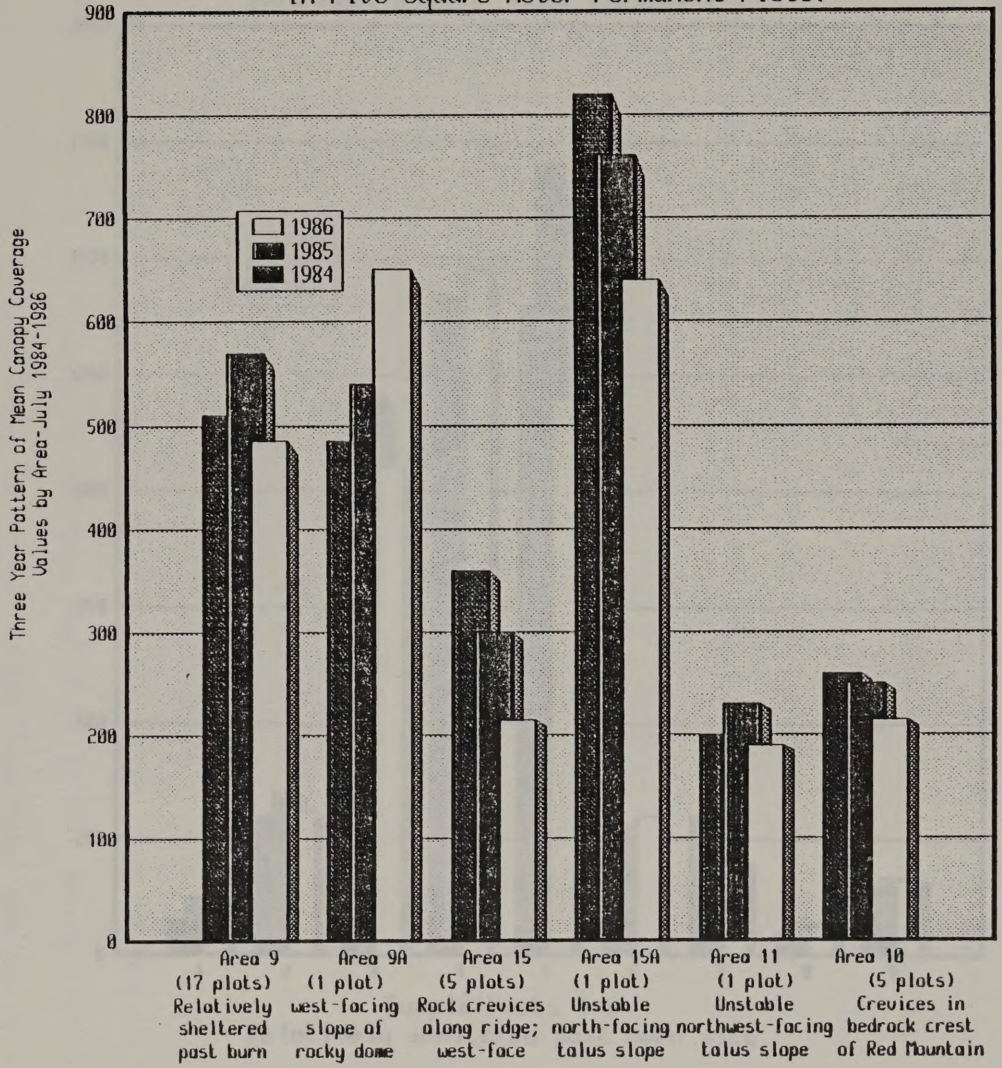
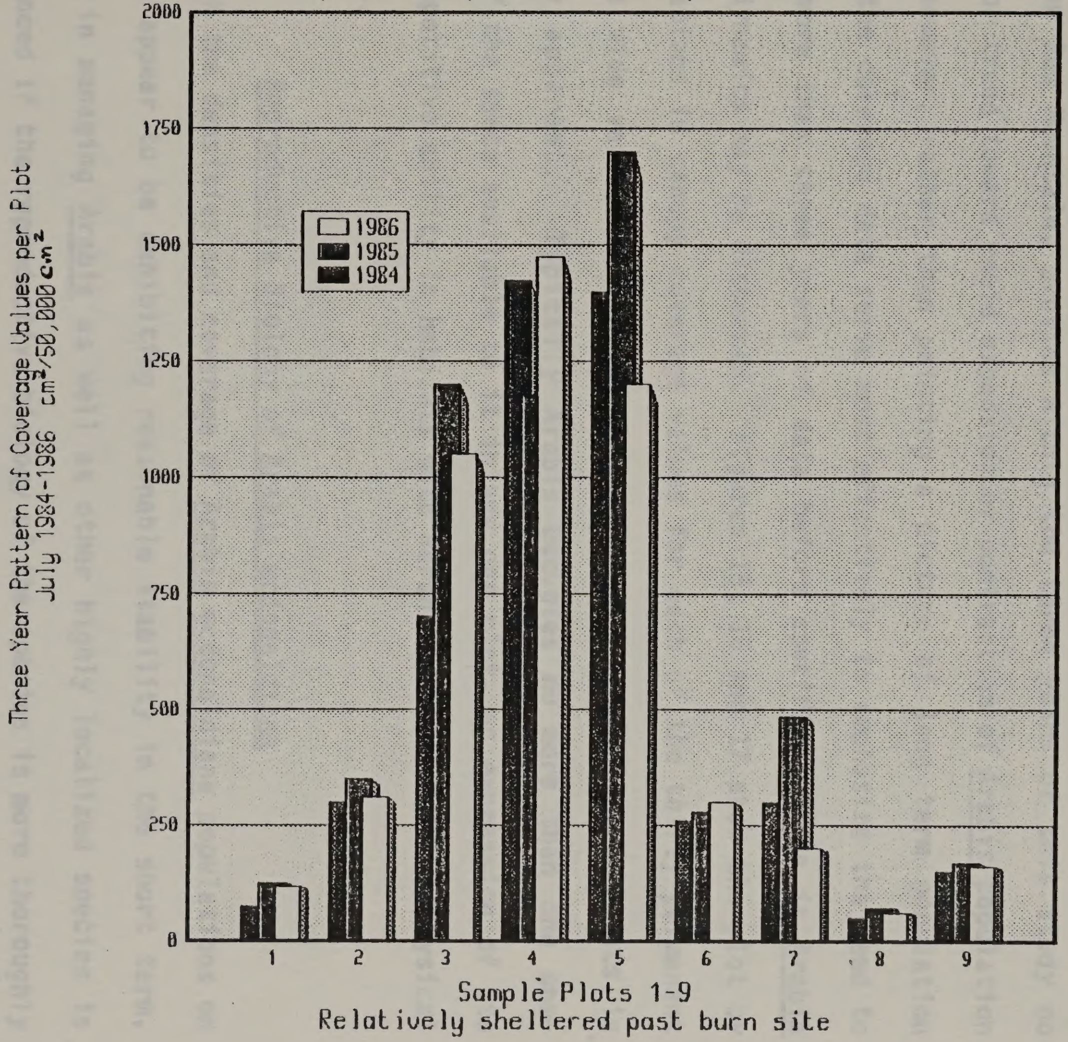


FIGURE 15

Fluctuations in Canopy Coverage Values of *Arabis mcdonaldiana* over a three year period as observed in five square meter permanent plots. Area 9:plots 1-9



sampled with the greatest intensity (17 plots) and possessing the highest Arabis densities, canopy coverage values showed neither an obviously increasing or decreasing trend, the small variations seen in annual values falling well within fluctuations expected by chance alone. In general the coverage data, representing the most accurate reflection of the overall health of Arabis on Red Mountain, provide within the three years of this study no indication or trend toward rapid expansion or contraction of Arabis population biomass. However, rather than painting a picture of long term population stability, the coverage data serve most effectively to emphasize the need to accumulate more than three years of data before specified trends in Arabis population dynamics may be discerned. Figures 15, 16 and 17 show the plot by plot fluctuations in canopy coverage values for each of the thirty permanent plots. The wide variance in coverage values within and between plots is immediately apparent. Typically Arabis occupies no more than one one-hundredth of the space available to it in any one plot, an expression of its relative competitive ability in habitats with harsh biotic as well as physical environments.

Reproductive Biology of Arabis mcdonaldiana

Although the densities and coverage of Arabis mcdonaldiana populations on Red Mountain appear to be exhibiting reasonable stability in the short term, one's skill in managing Arabis as well as other highly localized species is greatly enhanced if the reproductive biology of the species is more thoroughly understood. As a contribution to this body of knowledge, the reproductive cycle including anthesis, pollination ecology, breeding system, silique maturation and seedling germination success were explored over a variety of habitats. Anthesis in Arabis mcdonaldiana begins as early as mid February and

FIGURE 16

Fluctuations in Canopy Coverage Values of
Arabis mcdonaldiana
over a three year period as observed in five square meter permanent plots.
Area 9 : plots 10-17 and Area 9A.

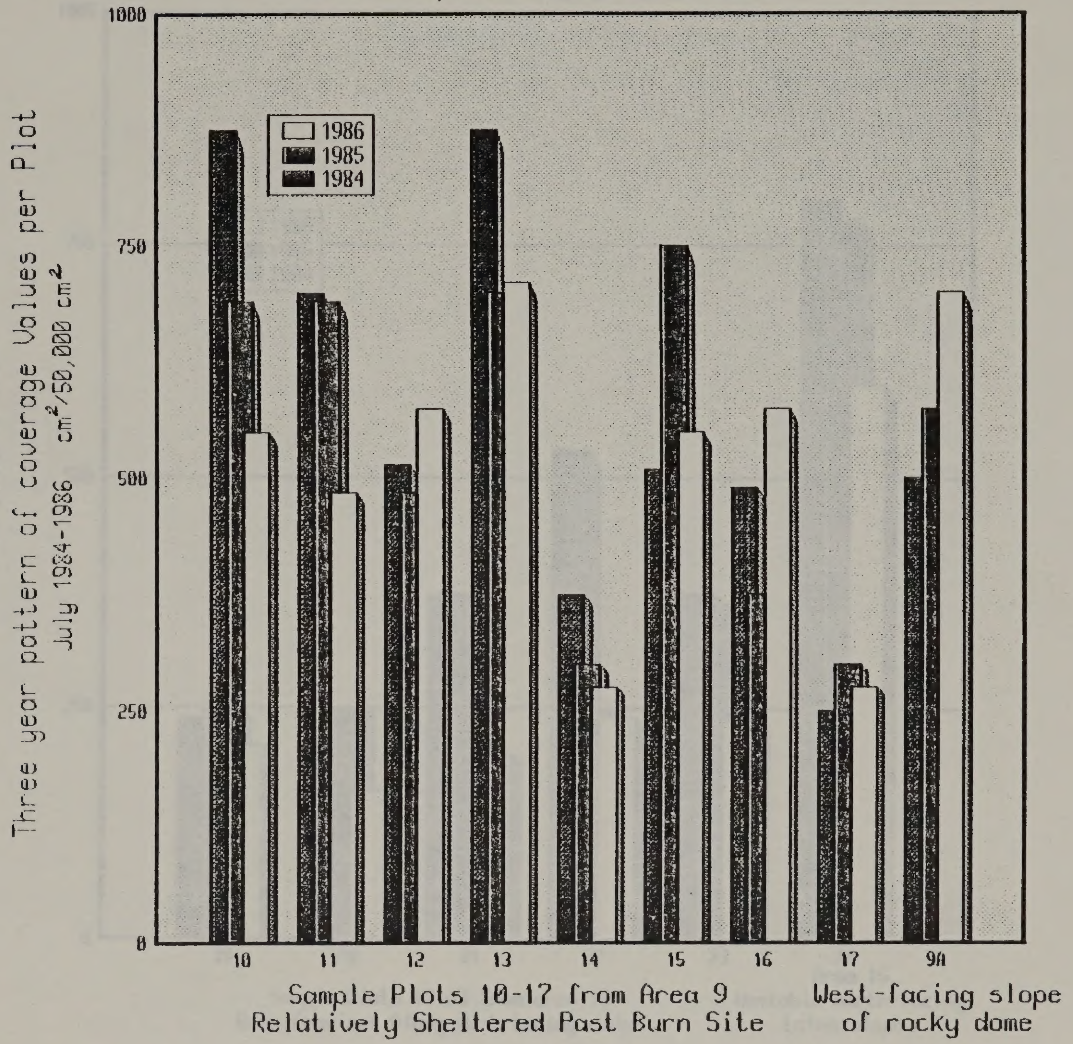


Figure 17A

Fluctuations in Canopy Coverage Values of *Arabis mcdonaldiana* Over a Three Year Period as Observed in Five Square Meter Permanent Plots.

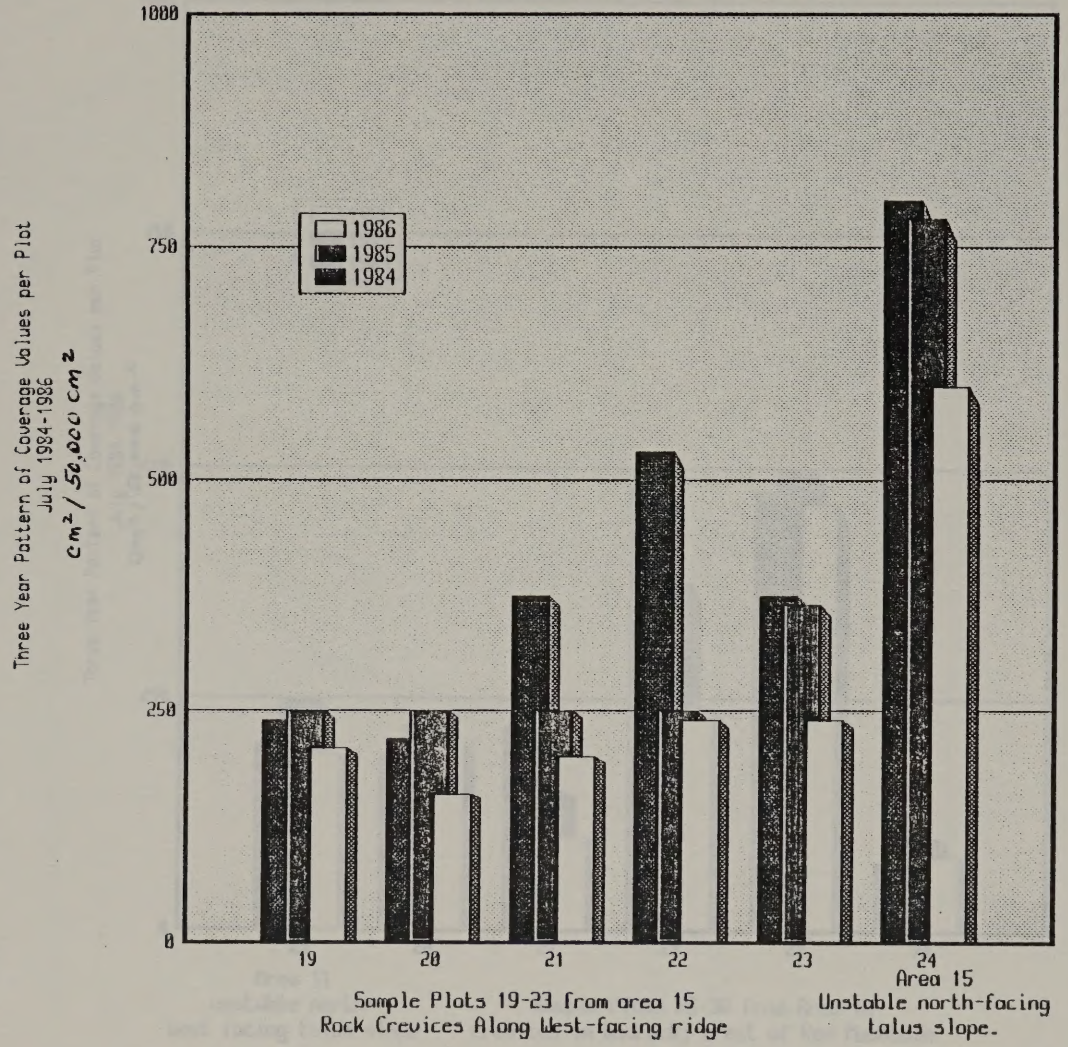


Figure 17B

Fluctuations in Canopy Coverage Values of

Arabis mcdonaldiana

Over a Three Year Period as Observed in Five Square Meter Permanent Plots.

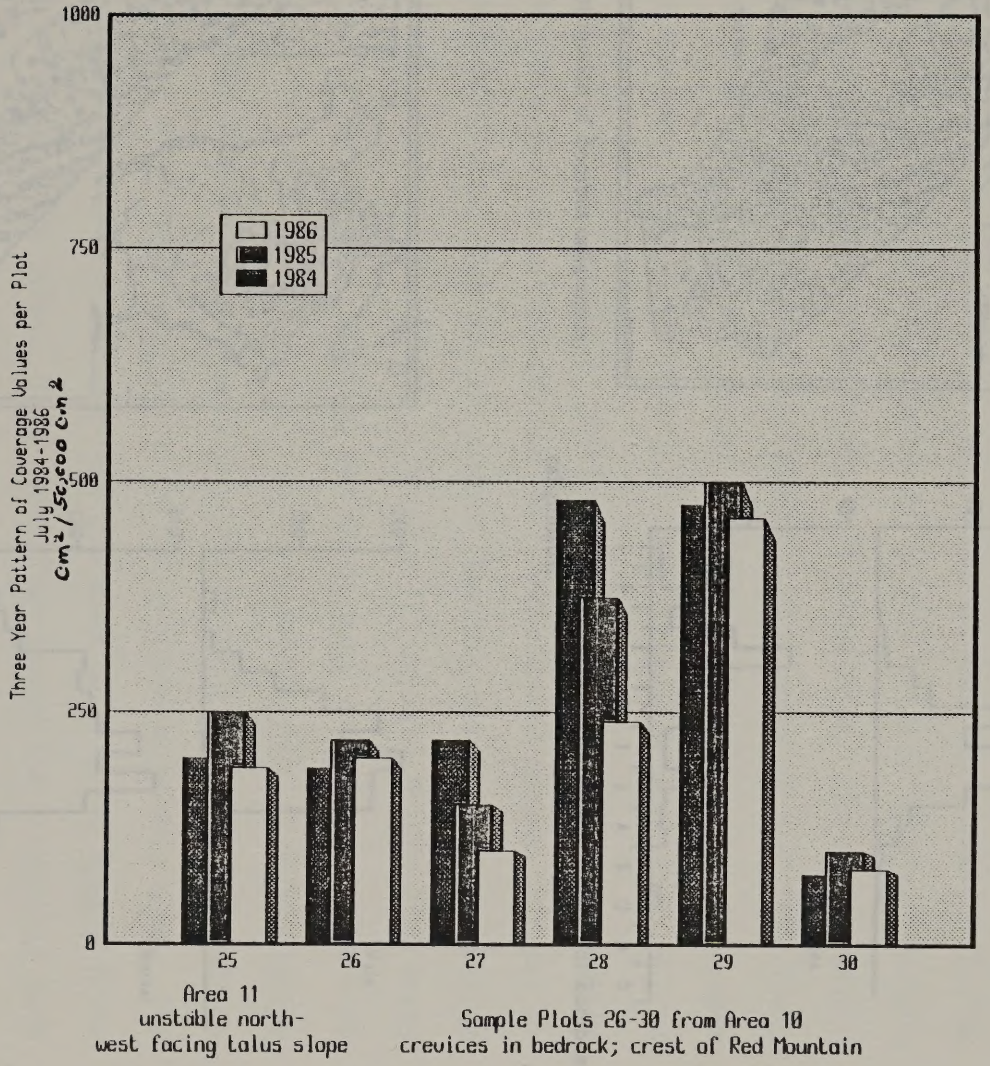
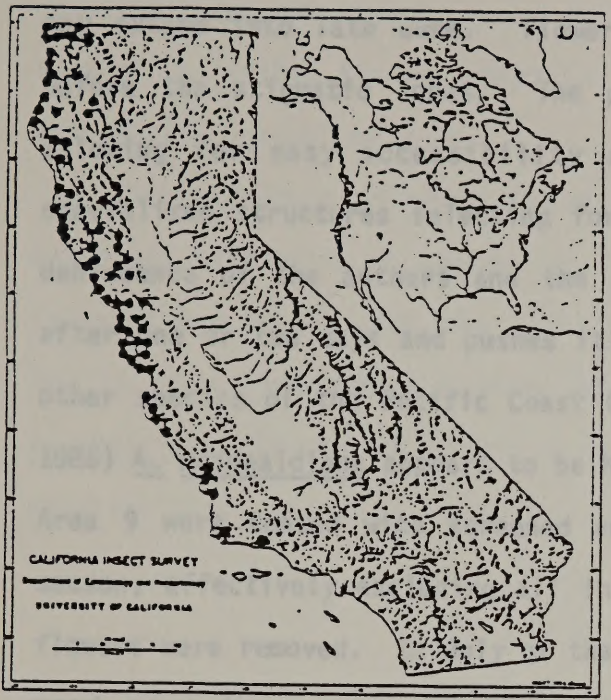
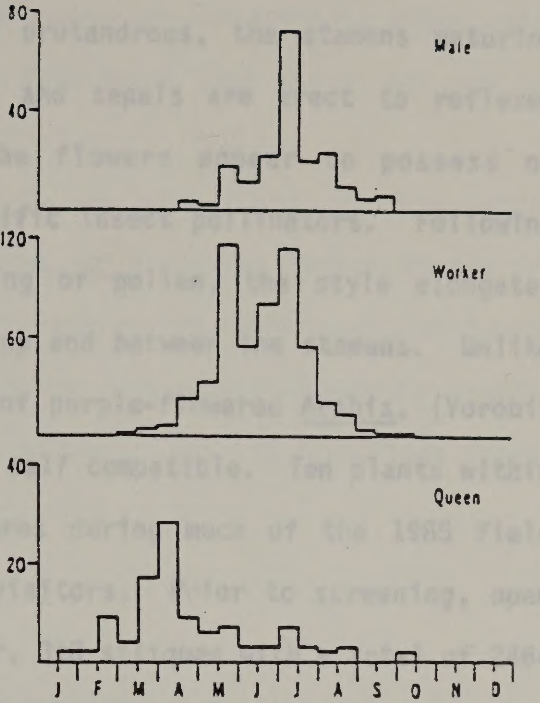


Figure 18

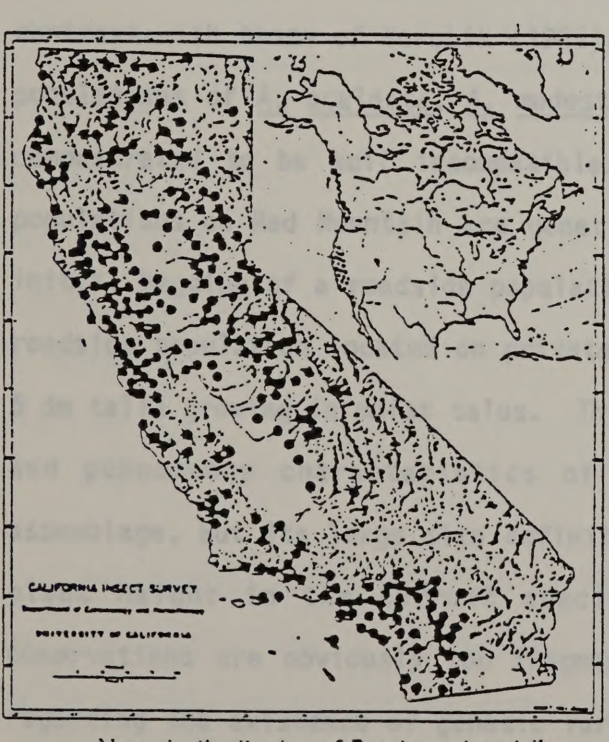
Geographical Distribution and Seasonal Flight Activity of *Bombus caliginosus* and *B. edwardsii*



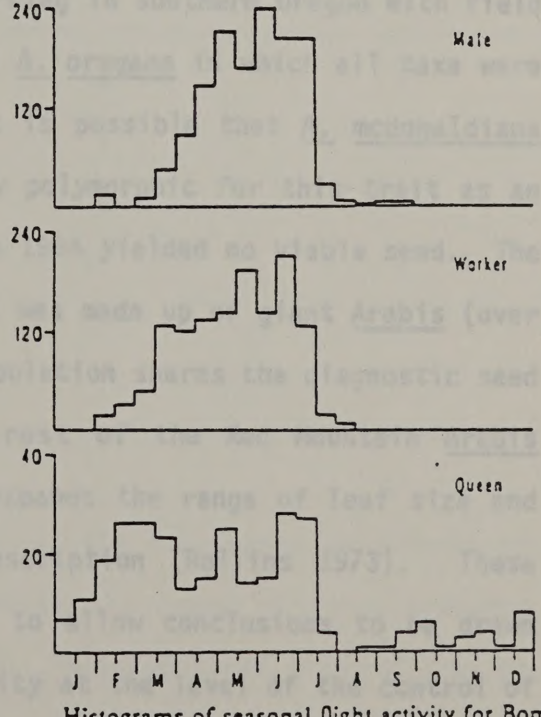
Nearctic distribution of Bombus caliginosus.



Histograms of seasonal flight activity for Bombus caliginosus.



Nearctic distribution of Bombus edwardsii.



Histograms of seasonal flight activity for Bombus edwardsii.

From Thorp, R.W., Horning, D.S. and L.L. Dunning. 1983. Bumble bees and cuckoo bumble bees of California. Bulletin of the California Insect Survey Vol. 23. Univ. of California Press

may extend into late June. Flowers are protandrous, the stamens maturing before the stigmatic lobes. The petals and sepals are erect to reflexed allowing for easy accessibility and the flowers appear to possess no specialized structures selecting for specific insect pollinators. Following dehiscence of the anthers and the shedding of pollen, the style elongates after one or two days and pushes its way up and between the stamens. Unlike other species of the Pacific Coast Group of purple-flowered Arabis, (Vorobik 1985) A. mcdonaldiana appears to be highly self compatible. Ten plants within Area 9 were tented with screened enclosures during much of the 1985 field season, effectively excluding all insect visitors. Prior to screening, open flowers were removed. In July of that year, 310 siliques with a total of 2464 seed were harvested from these tested plants. The seed, averaging 7.95/silique, were planted on greenhouse soil and after 3 months, a total of 2090 seed had germinated for an 85 percent success rate. These results contrast with those of Vorobik (1985), working in southern Oregon with field populations of A. aculeata, A. modesta and A. oregana in which all taxa were demonstrated to be self incompatible. It is possible that A. mcdonaldiana populations on Red Mountain are genetically polymorphic for this trait as an initial bagging of a roadside population in 1984 yielded no viable seed. The roadside population located on private land was made up of giant Arabis (over 5 dm tall) growing in moist talus. This population shares the diagnostic seed and pubescence characteristics of the rest of the Red Mountain Arabis assemblage, but its large size definitely expands the range of leaf size and plant height in the current species description (Rollins 1973). These observations are obviously too fragmentary to allow conclusions to be drawn regarding the existence of genetic variability at the level of the control of

compatibility, but they do point to the existence of considerable phenotypic variability within the Red Mountain Arabis population that may or may not be genetically controlled.

Although Arabis flowers appear early in the spring and are frequently saturated with rain or covered by late snows as witnessed during visits in February and March, 1985 and 1986, flowers receive frequent insect visitors during clear weather. A total of 112 hours were spent observing *Arabis mcdonaldiana* flowers and recording insect visitors. Table 2 summarizes these observations.

Table 2

Insect Visitors to the Flowers of *Arabis mcdonaldiana*

Location:	Area 9 60 hours - March April, May	Area 10 38 hours - March April, May	Area 15 14 hours - April May
Syrphidae	8	2	1
Bombylius species	4	1	3
Apis melifera	6	2	2
Bombus caliginosus	24	17	8
B. edwardsii	20	13	4
Pieridae	2	1	0

Bee species were identified by Wasbauer at the California Department of Food and Agriculture in Sacramento. In general all insect visitors appeared to be capable of pollinating Arabis flowers. Most appeared primarily to be

collecting pollen and as stigma and anthers are readily profferred in the mature flower, successful transfer of pollen from anthers in the same flower or from adjacent flowers in the relatively congested Arabis inflorescence to the receptive stigmas appeared highly probable. The most frequent flower visitors were bumble bees of the genus Bombus which moved freely between Arabis and the pinkish-white inflorescenes of Arctostaphylos canescens, in flower throughout the period of Arabis anthesis. Both species of bumble bees encountered pollinating Arabis flowers are tree nesters or ground dwellers, building their nests in abandoned rodent burrows, hollow trees, bird nests or brush piles. One such nest in a rodent burrow was encountered adjacent to Area 9 and appeared to contain from 50 to 100 individuals. Each of these bee taxa are widespread in the coast ranges of California, B. edwardsii occurring in the Sierras, southern California and the Great Basin as well (Figure 18). Both taxa are active throughout the flowering period of Arabis mcdonaldiana (Thorp, et al. 1983). Insect visitors in general appeared to restrict themselves to the tops of individual Arabis flowers gathering pollen, only infrequently penetrating to the base of the developing silique. Nectar production does not appear to be a significant attractant for insect pollinators and insufficient nectar was observed to test for variation in nectar quality or periodicity in mono and disaccharide production.

Impact of Predation on Reproductive Potential

In addition to the insect pollinators treated in the previous section, other animal species appear to have an impact on Arabis' reproduction success. According to Goforth (1982), predation on Arabis by native animals occurs at Red Mountain. R. Sutherland (U.S. Fish & Wildlife Service 1984) has observed that well over half of all plants on Red Mountain lose their fruiting stems in

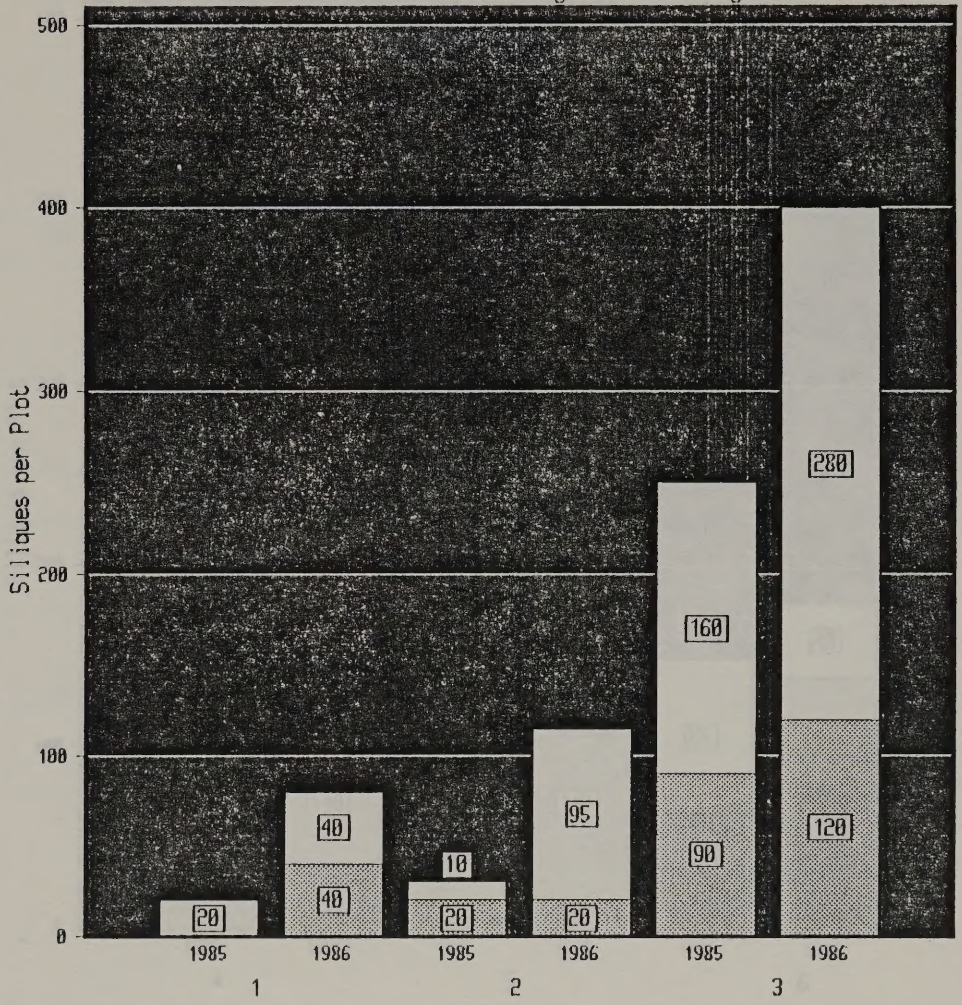
Figure 19A

Reproductive Success of

Arabis mcdonaldiana

in Permanent Plots 1-3 as Measured by Siliques

Produced and Surviving to Maturity



Shaded portion of column denotes siliques escaping predation.

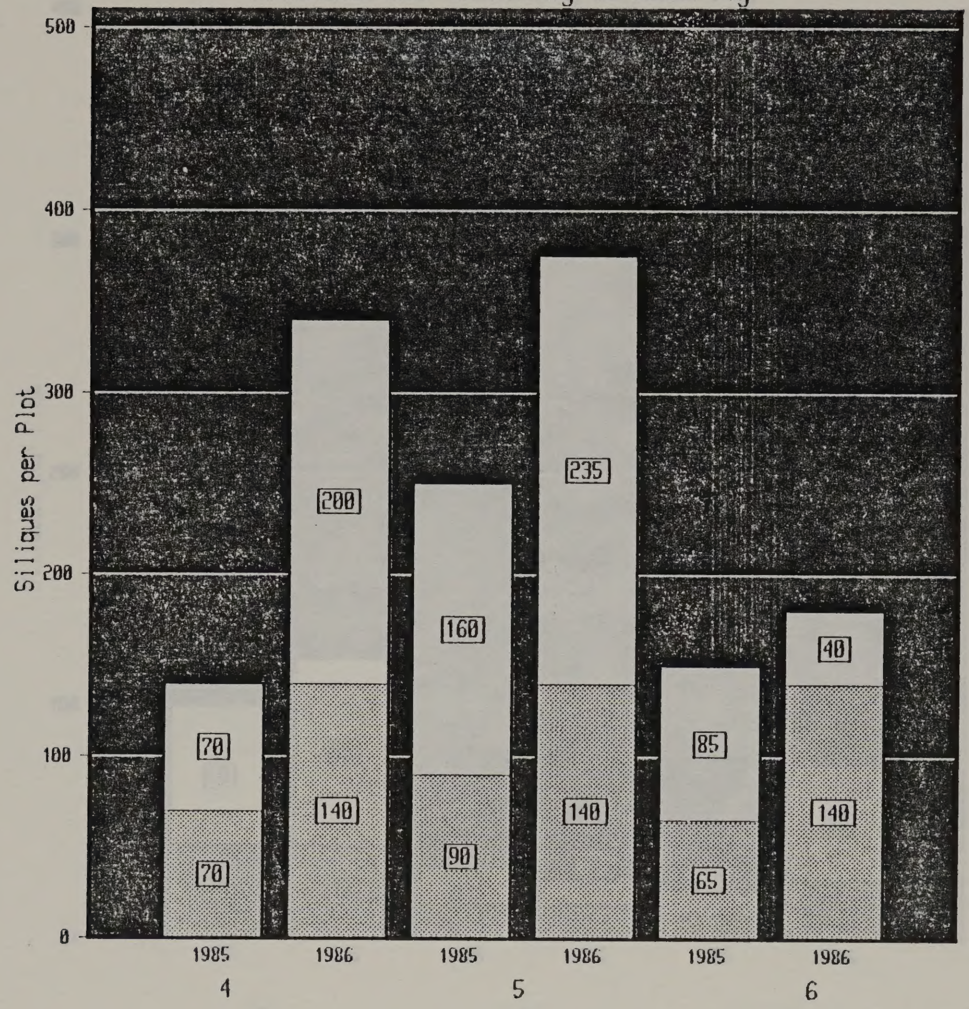
Figure 19B

Reproductive Success of

Arabis mcdonaldiana

in Permanent Plots 4-6 as Measured by Siliques

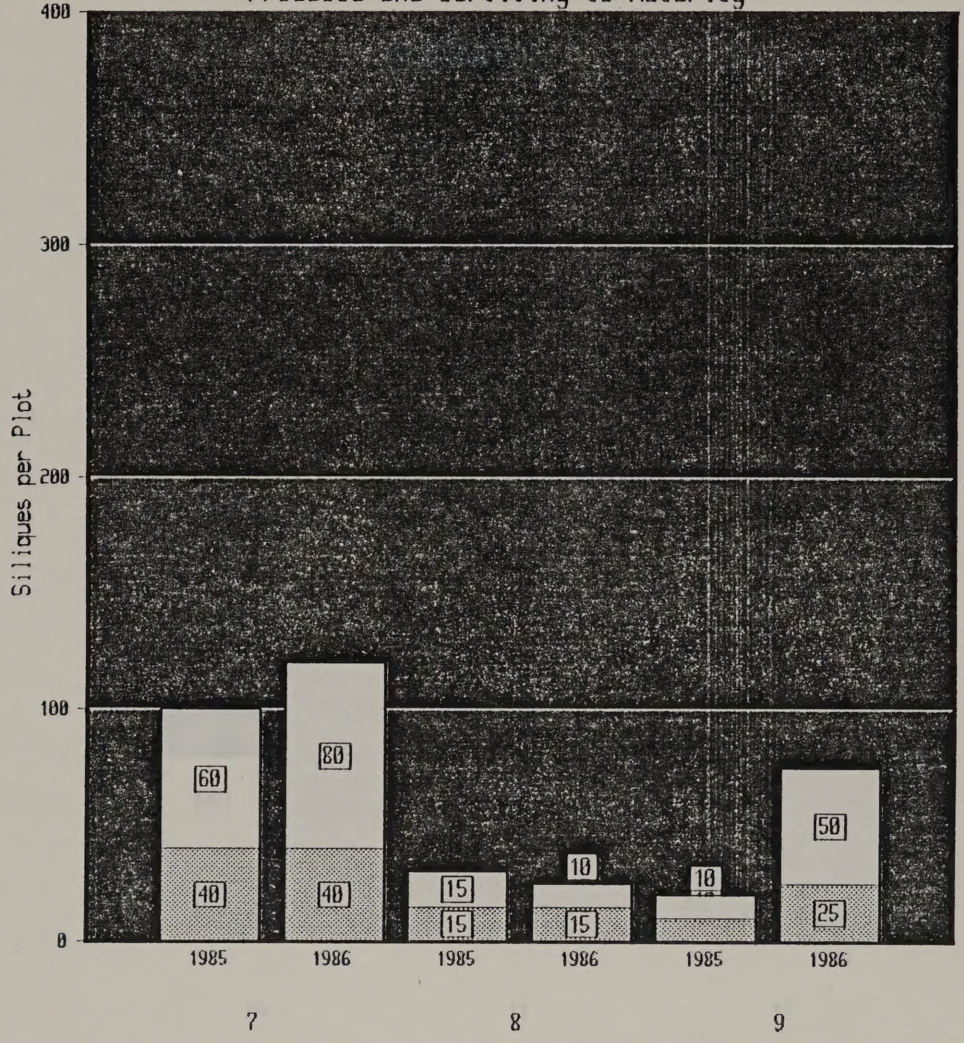
Produced and Surviving to Maturity



Shaded portion of column denotes siliques escaping predation.

Figure 19C

Reproductive Success of *Arabis mcdonaldiana* in Permanent Plots 7-9 as Measured by Siliques Produced and Surviving to Maturity



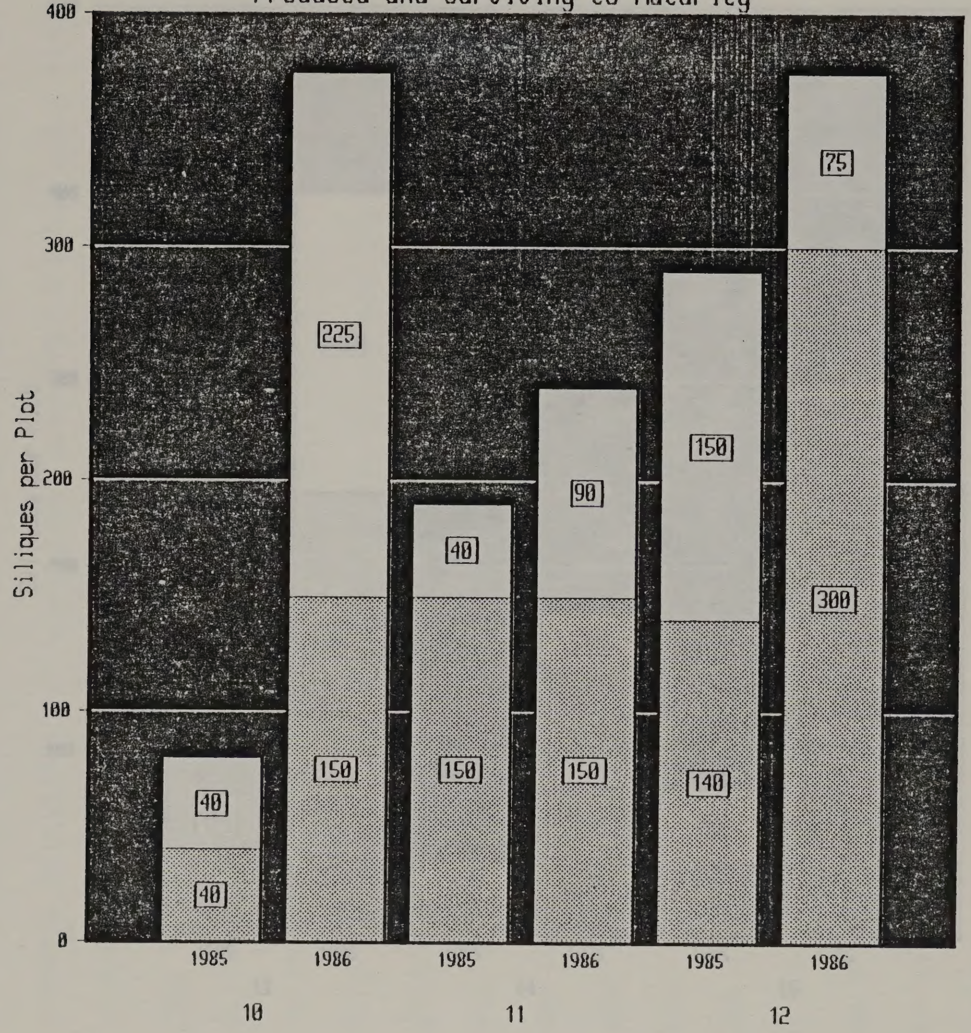
Shaded portion of column denotes siliques escaping predation.

Figure 19D

Reproductive Success of

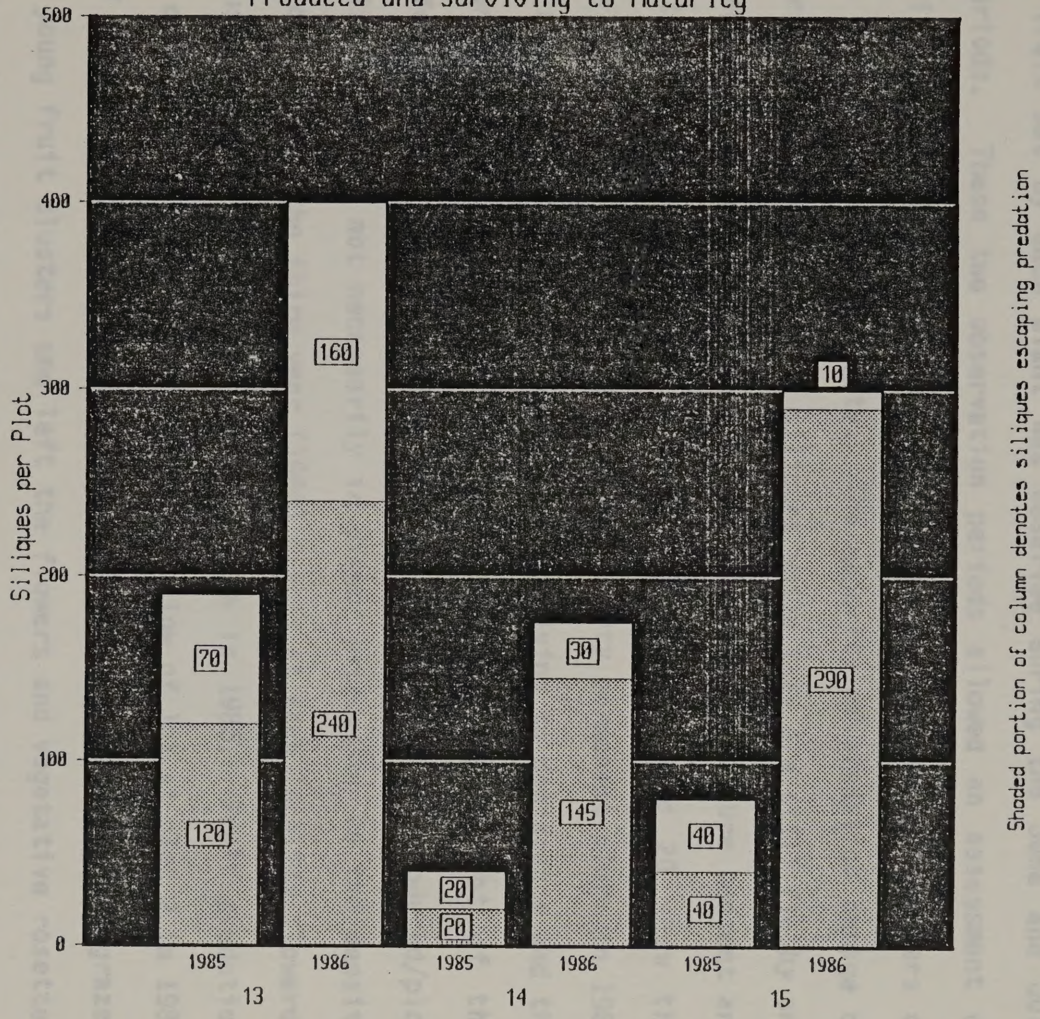
Arabis mcdonaldiana

in Permanent Plots 10-12 as Measured by Siliques Produced and Surviving to Maturity



Shaded portion of column denotes siliques escaping predation.

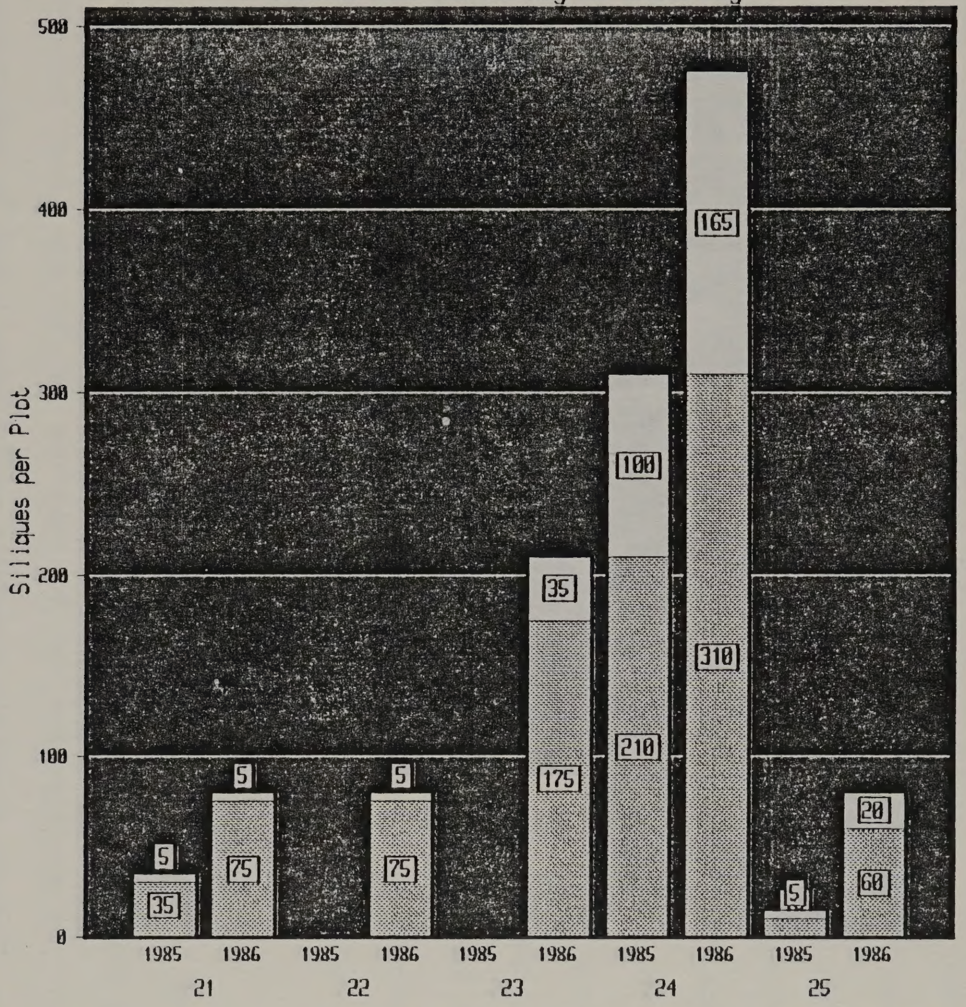
Figure 19E
Reproductive Success of
Arabis mcdonaldiana
In Permanent Plots 13-15
Produced and Surviving to Maturity



a manner suggesting predation. Initial observations during the first year of this study reinforced these conclusions and an assessment of the specific impacts of predation on Arabis reproductive success appeared essential. Within the thirty permanent 5 m^2 plots, reproductive success as measured by numbers of fruit set by each plant was observed during the June and July sampling periods. These two observation periods allowed an assessment of initial fruit set following anthesis followed by a census of the numbers of young fruit that survived to maturity. The majority of predation damage on Arabis occurs to the young unripened siliques while they are still fleshy and rapidly elongating. Once the siliques dry, losing their moisture content and beginning to dehisce, predation ceases. Figures 19 and 20 show the reproductive success of Arabis on each of the thirty permanent plots in 1985 and 1986 as measured by siliques produced and surviving to dehiscence and the dissemination of seed. As can be seen by comparing the height of the histograms for 1985 and 1986 at each plot, the number of fruit produced/plot varies significantly and not necessarily in direct proportion to the density of Arabis/plot. During the third year (1986) Arabis at each locality flowered more vigorously and more fruit were produced than in 1985. Fruit predation also varied considerably from site to site from a low of 10% at plot 2 in 1986 to a high of 100% at plot 30 in the same year. Surprisingly, predators grazed only on the young fruit clusters and left the flowers and vegetative rosettes alone. Silique loss usually occurred by the complete infrutescence being cut off about 1 cm above the base of the plant. No actual grazing of siliques was observed by this investigator, but to eliminate two obvious sources of potential predation, seven 1 m^2 bird and rodent exclosures were constructed of wire mesh (mesh diameter 2 cm) and placed over flowering Arabis plants during

Figure 20A

Reproductive Success of
Arabis mcdonaldiana
in Permanent Plots 21-25 as Measured by Siliques
Produced and Surviving to Maturity

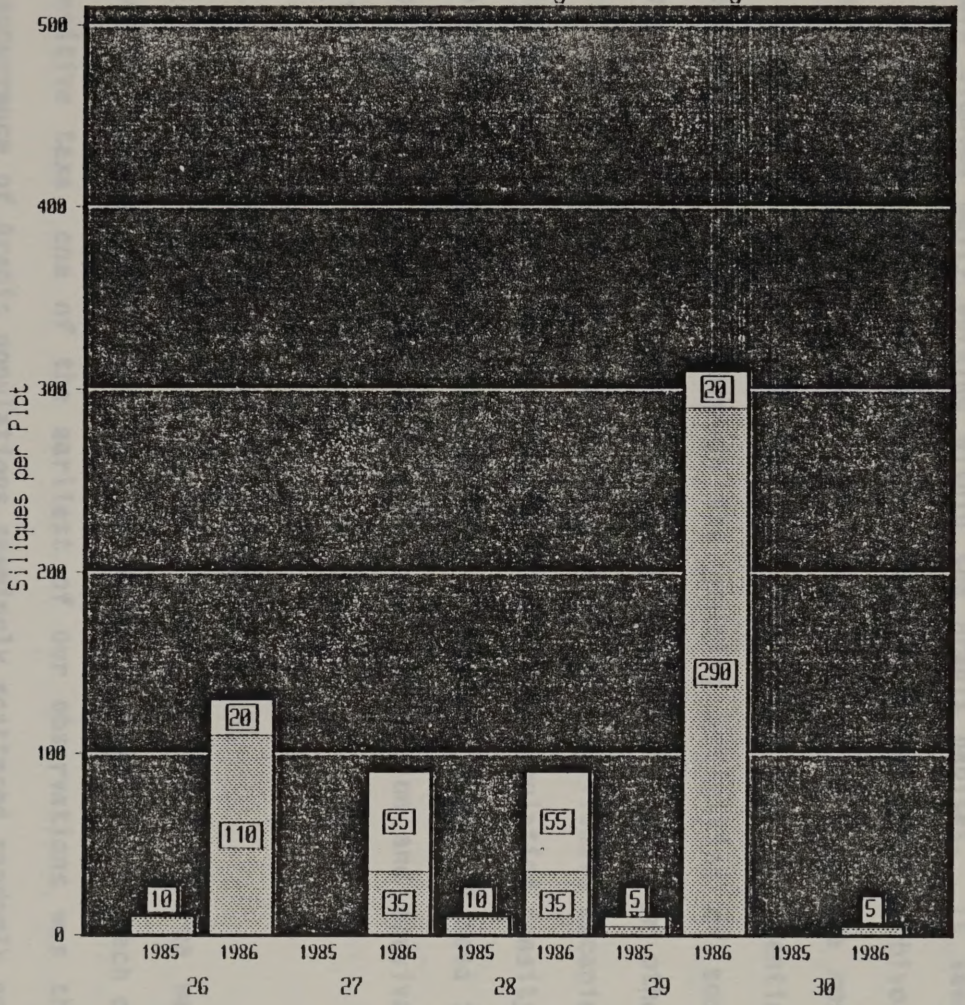


Shaded portion of column denotes siliques escaping predation.

Blank spaces indicate plots in which no individuals flowered in 1985.

Figure 20B

Reproductive Success of
Arabis mcdonaldiana
in Permanent Plots 26-30 as Measured by Siliques
Produced and Surviving to Maturity



Shaded portion of column denotes siliques escaping predation.

Blank spaces indicate plots in which no individuals flowered in 1985.

1985. All plants thus enclosed developed normally and experienced no loss of siliques during the 1985 field season. In contrast, adjacent plants within the permanent plots suffered from 10 to 70 percent predation. During a total of 420 trap nights, ten nocturnal brush mice (Peromyscus boylei) were captured in our live and snap traps and numerous Sonoma chipmunk, Gray squirrel and Chickaree were sighted daily working within the Arabis habitat. It seems likely that at least one of these species of rodents is the major herbivore predator utilizing Arabis siliques. Figures 19 and 20 indicate most populations appear to be highly vulnerable to considerable loss of potential seed and reproductive potential through the grazing activities of some organism larger than 2 cm in diameter (probably the brush mouse) or other small rodents. However, the annual production of seed by individuals escaping silique predation appears adequate to maintain the present population density. Likely of more critical concern to the survival of any year class of seed is the availability of appropriate safe sites for germination and survival through the first hot dry summer (Harper, et al. 1965).

Identification of Essential Arabis Habitat

During the initial stages of this study as the Red Mountain area was being systematically traversed to complete maps of the distribution of each of the four sensitive taxa, one of the earliest of our observations was the paradoxical occurrence of Arabis populations seemingly scattered randomly and quite sparingly over what appeared to be an abundance of potentially occupiable habitat. Arabis appeared to prefer open rocky areas and this sort of habitat was in good supply at 4000 feet on Red Mountain. Why then isn't the species considerably more abundant and widely distributed within the study area? This is not an academic question. The Recovery Plan (U.S. Fish &

Wildlife Service 1984) calls for the protection of sufficient habitat to insure the well-being of rock-cress. Although the major threat to McDonald's rock-cress is undeniably the proposed mining activities on Red Mountain and any disturbance of this magnitude would significantly impact any plant species restricted to Red Mountain, the effective long term management of the Red Mountain Study Area assuring the survival of McDonald's rock-cress as well as the other three narrowly endemic plant taxa demands a more critical understanding of the species' habitat requirements. For terrestrial plants, the most critical stage in the lifecycle is the period of seedling establishment (Harper 1977). The dominant element of the germinating seed's environment is the soil.

Soil experiments

The ultramafic rocks comprising Red Mountain have degraded into basically two soil taxa--Huse and Cornutt soils (the soil classification of Red Mountain used in this paper is that cited by Jenny). Existing heterogeneity may be further classified as the area is resurveyed by the Soil Conservation Service (H. Jenny in U.S.F.W.S. 1984). Huse soils are distinctly red, rocky and shallow, even on nearly level terrain, and appear to form the exposed peaks, ridges and steeper slopes of Red Mountain. Cornutt soils are more prevalent and usually deeper, reaching five feet in the level areas and basins between rises and ridges. The deep red Cornutt soils on Red Mountain share many of the pedological attributes of lateritic soils of tropical regions, and indicate to some soil scientists that this area was subjected to a tropical climate in the past. Jenny (U.S.F.W.S. 1984) questions this view as running counter to current concepts of biotic evolutionary trends, geological history and climatic change in California, but the jury is still out on the geological

interpretation of Red Mountain's origin and development and additional data must be gathered before existing controversy will be resolved.

Arabis mcdonaldiana appears to be restricted to the more shallow Huse soils. All known populations of this species occur on soils of this description. The largest Arabis population (Area 9) abruptly truncates its distribution in the saddle between Red Mountain Baldy and the neighboring ridge to the east. This distribution boundary is coincident with the beginning of a zone of deep red Cornutt soil, although no obvious explanation for this edaphic selectivity is apparent.

One testable hypothesis to explain this soil specific distributional pattern is that soil quality is acting as a sieve allowing only seeds of certain plant species to become established. Genetic adaptations of plants to ultramafic soils have been well documented (Kruckeberg 1954; Mansberg and Wentworth 1984; Proctor, J. 1971). In general, ultramafic ecotypes have not been found to nutritionally require serpentine soils but rather to require the soil's rigorous environment as a means of eliminating maladapted competitors. The nature of Arabis mcdonaldiana's requirement for ultramafic substrate had not been previously investigated.

Using Arabis seed (tested to be 98% viable by germination tests conducted on greenhouse loam) lots of 75 seed were planted in 8 X 10 inch trays containing equal amounts of four types of soil:

1) Cornutt - red highly oxidized soil from Red Mountain
2) Huse - rocky less highly oxidized soil from Red Mountain
3) Hugo - non ultramafic soil from Mail Ridge adjacent and east of Red Mountain
4) Greenhouse loam

Each soil was mixed with fifty percent river sand to lessen the impact of compaction in the fine red Cornutt soil samples from Red Mountain, and each soil trial was replicated three times. These twelve trays (each planted with seventy-five seed) were given equal amounts of water every two to three days. After one month the following counts of seedlings were obtained:

Table 3

Seedlings Appearing in Each of the Three Replicates*

	Replicate Number 1	2	3
Cornutt Soil (Red Mountain)	51	72	46**
Huse Soil (Red Mountain)	44	66	47
Hugo Soil (Mail Ridge)	36	55	42
Greenhouse loam	45	65	63

* 75 seed were planted per tray

** Differences between the mean numbers of seedlings growing on each soil were not significant at the 95% level.

At the time of this census, there was no significant difference in the ability of Arabis to germinate and survive with abundant water on the various soil types. Clearly Huse soil on Red Mountain is not providing Arabis with some unique component critical to its survival as a seedling. These trays presently remain intact and have now been growing for approximately two years. They were transferred from the greenhouse to my backyard and received normal hot, dry Sacramento summer weather and more recently considerable amounts of rain. The red Cornutt soil trays became brick hard over the summer and these

seedlings showed little growth. However the Red Mountain Huse soil trial continues to do well--but no better than the seedlings growing on nonserpentine soil. Kruckeberg (1954) found that most serpentine endemics would grow as well if not better on nonserpentine soil under controlled conditions. A plant's restriction to serpentine in the field appeared to be more related to its tolerance of serpentine and its inability to compete effectively with nonserpentine adapted taxa on normal soils.

Seedling and Transplant Experiments

Although the greenhouse seed germination trials demonstrated that *Arabis* did not intrinsically require a particular type of soil for germination and growth under controlled conditions, over the term of the experiment seedlings did appear to grow more vigorously on the more well drained Huse soils as compared to the finer Cornutt soils. These results were obtained from greenhouse trays of soil and likely do not accurately reflect conditions in the field. However, these initial results began to stimulate our interest in the question, "Why doesn't *Arabis mcdonaldiana* occur more widely within the open rocky habitats presently devoid of the species?" In order to gain some additional understanding of this phenomenon, in November 1985, in between fall rains, 30 one m^2 plots were individually planted with 100 *Arabis* seed to monitor seed germination success over a wide range of Red Mountain habitats presently unoccupied by the species. Several of these plots received one or two one-year-old transplants reared in the greenhouse as well.

During the 1986 field season these plots were revisited (May 10, 18 and July 12) and the health of transplants and seedling counts were recorded. The location and physical characteristics of each of the seeding sites are listed in Appendix 1.

The most striking result of this experiment was the extremely poor germination success exhibited by Arabis mcdonaldiana over a wide range of habitats. Two seedlings resulted from a total scattering of 3000 seed over an area of 30 square meters. These two seedlings appeared in Plot 1, a steep south facing slope of a mining test pit, a habitat that I would have predicted to be one of the least satisfactory for the species' establishment.

An explanation for the Arabis seeds' extremely poor showing over a range of seemingly occupiable habitats is not immediately obvious. Laboratory tests of seed viability immediately prior to the field tests indicated the seed had a 95-97 percent germination potential on watered soil and these results tend to negate the possibility that Arabis seed require aging or scarification prior to germination. Genetic polymorphisms for the timing of seed germination also appear unlikely in this long lived herbaceous perennial. Why then do Arabis seeds fail to grow in habitats almost identical to those in which they now occur? The enormity of this paradox is somewhat reduced when we observe what the normal seed germination success rate is within established Arabis populations. As was seen in Figures 19 and 20, the reproductive success per plot as measured by the number of siliques brought to maturity varies considerably from plot to plot as well as from Area to Area.

In 1985-86, plants in Area 9 (the protected burn site) were reproductively most successful producing an average of 399 seed and 5 seedlings per 5 m^2 plot. Arabis in Areas 10 and 15, however, achieve between 20 and 52% of Area 9's output of seedlings with only a seed production of 3 and 14% that of the former. The open exposed sites of Areas 10 and 15 appear to allow for higher (probabilities of) seedling establishment per seed. Considering data from all plots, an average seed has about a one in one

hundred chance of finding a safe germination site within the Study Area. It becomes immediately apparent that Arabis, even in its preferred habitat, has a relatively low rate of seed germination success. Transplants in the seeding sites in general also fared poorly, surviving currently only at the mining test pit sites at Plots 2, 3 and 4. Transplants suffered heavy predation over the winter months; perhaps they represented a highly palatable resource in an otherwise largely barren area, and all but 5 of 25 original transplants ranging in size from 3 to 13 cm in diameter were completely grazed and/or torn out of the ground by herbivores. The transplants' vulnerability to predation was likely enhanced by their healthy succulent texture stemming from a year's growth under high moisture conditions in Sacramento. The transplants were easily 10 times as large as seedlings of the same age germinating on Red Mountain. One additional explanation for the rapid disappearance of the imported (greenhouse) seedlings may be that they possessed a higher palatability due to their being grown on greenhouse soils. The studies of Reeves and Baker (1984) and Gabbrielli and Pandolfini (1984) working with Thlaspi and Alyssum in New Zealand and Italian serpentine habitats respectively demonstrate that these crucifer genera typically concentrate between 4960-12,400 g/g^{-1} of nickel (dry weight) in their rosette leaves. Red Mountain Arabis may accumulate heavy metals in high concentrations as well, and these chemical loads may serve to reduce herbivore predation significantly.

The seedling transplant experiment provided little data of value enabling one to more accurately describe the critical Arabis habitat. The concept of germination safe sites explored ingeniously by Harper et al. (1965) called attention to the heterogeneity of the soil-seed interface and the selectivity

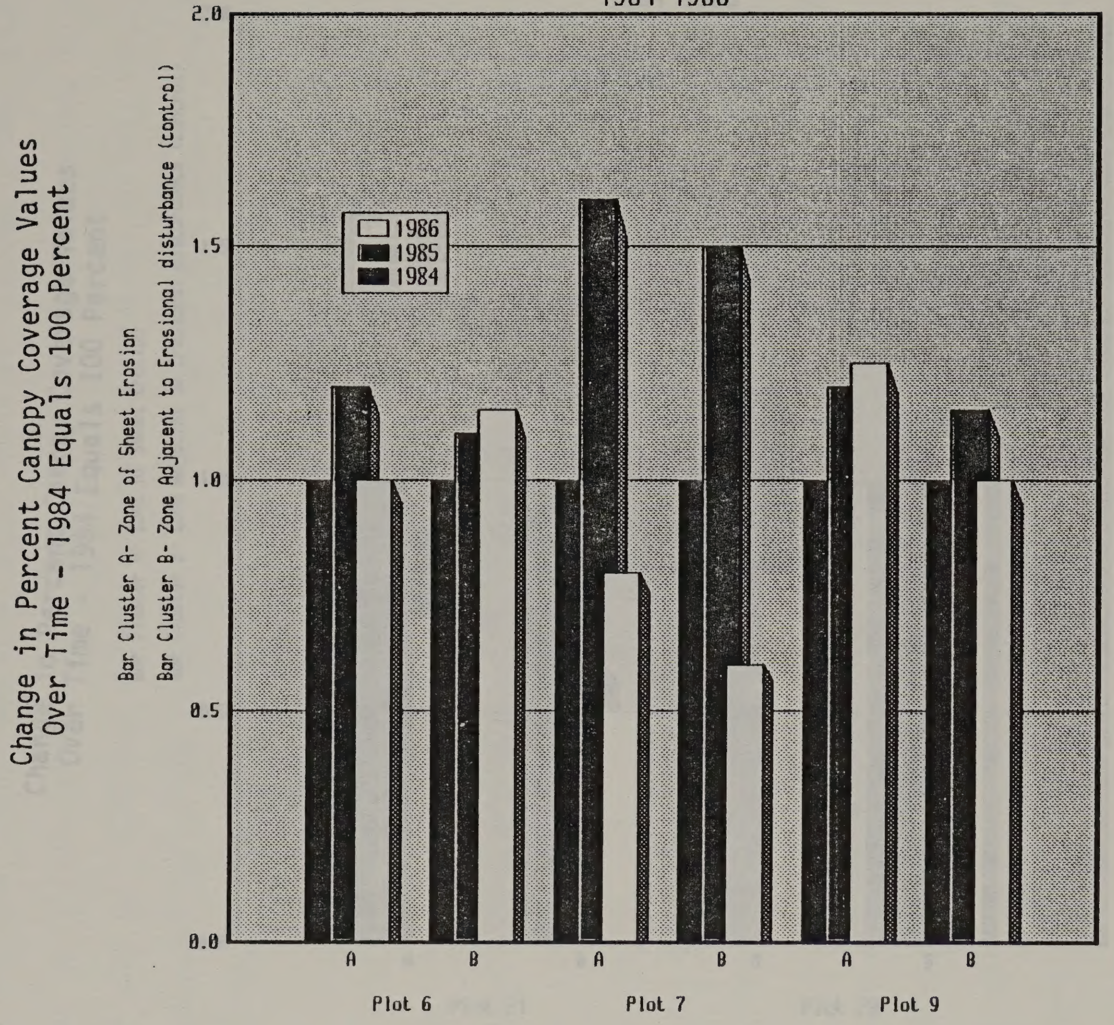
of different species of plants for unique microsite requirements. Within the permanent plots it is apparent that Arabis seeds will not germinate in heavy accumulations of pine needles, oak leaves or other debris. Areas experiencing consistent sheet erosion also would appear on first examination to be poor habitats for Arabis growth. However, within the five permanent plots exhibiting sheet erosion, the plants established within this zone grew as fast or faster than adjacent (control) plants (Figure 21).

Clearly, in the absence of additional data on the specific environmental conditions prevailing within each of Arabis mcdonaldiana's current habitats, a more accurate resolution of what constitutes critical Arabis habitat may not be possible. Such an indepth autecological study of each plant's microenvironment would undoubtedly be revealing as well as ecologically satisfying. However, the microrelief and microedaphic textures revealed may well prove to be too exacting and difficult to measure to be of practical use for managing the species. The probability of occurrence of Arabis mcdonaldiana on a site may have a stochastic component as well. Populations adapted to disturbed habitats--past burns, scree slopes, unstable erosion surfaces--are likely to be periodically eliminated locally from their rapidly changing habitats, and the occurrence of Arabis at any one location at any particular time is probably a function of the chance availability of a seed source adjacent to a recently modified environment.

Little is known of the relative vagility or dispersal potential of Arabis seed. Seed of Arabis mcdonaldiana are equipped with a narrow wing that could potentially assist in their aerial dispersal during periods of windy weather. Siliques dehisce, however, in July during relatively calm weather and the majority of seeds appear to fall close to the parent plant (personal

Figure 21A

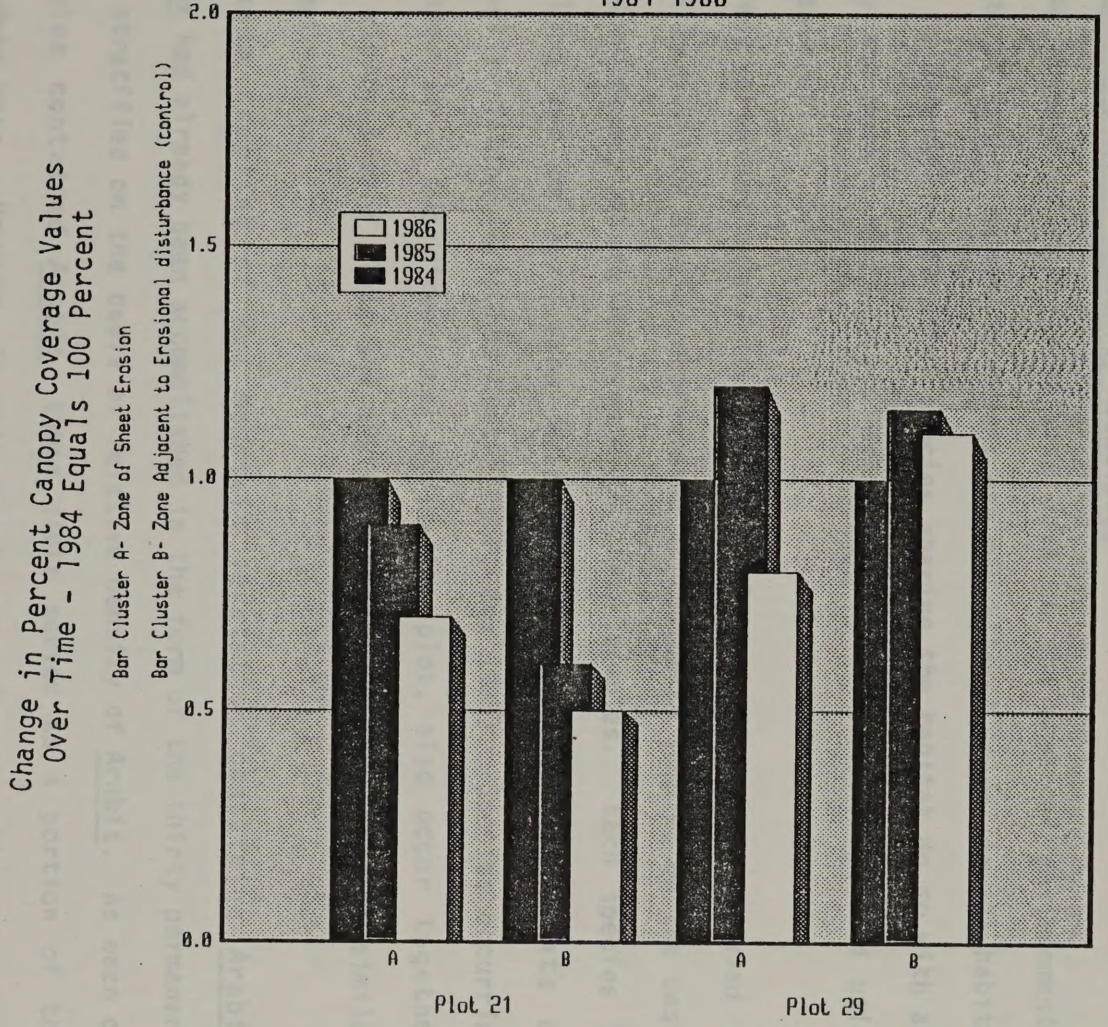
Change in Canopy Coverage of
Arabis mcdonaldiana
within and adjacent to areas of sheet erosion
1984-1986



Histograms depict three year changes in Arabis coverage values within and adjacent to areas of sheet erosion.

Figure 21B

Change in Canopy Coverage of
Arabis mcdonaldiana
within and adjacent to areas of sheet erosion
1984-1986



Histograms depict three year changes in Arabis coverage values within and adjacent to areas of sheet erosion.

observation). Subsequent distribution of seed is probably accomplished by sheet erosion and gravity. These mechanisms, however, are deficient in explaining the present distribution of most Arabis populations on the tops of mountains and ridges.

Multivariate Analyses of Community Associates

In the absence of more definitive data on the physical environmental requirements of Arabis on Red Mountain, one may attempt to define its habitat indirectly by determining if other species sharing the habitat do so with any consistency and more specifically: can Arabis' presence be predicted using indicator species?

Indirect gradient analysis, one type of ordination, may be used to mathematically position species encountered in community samples on the basis of their consistency of co-occurrence in these samples. Each species is located along two or more axes which represent major components of compositional variation (Bray and Curtis 1957, Cox 1985). Species occurring close together on a two dimensional ordination plot, also occur together frequently within sample plots and their co-occurrence may indicate similar habitat requirements.

A random sampling of Red Mountain vegetation containing Arabis mcdonaldiana had already been accomplished in the form of the thirty permanent 5 m^2 plots stratified on the basis of relative density of Arabis. As each of these samples contained Arabis, these plots served as a portion of the ordination data base. However, in order to increase the overall coverage of habitats on Red Mountain, thirty-four additional 5 m^2 plots were (randomly but systematically) located throughout the Study Area using a gridded overlay and two randomly generated coordinates within each of 34 regularly spaced sectors

(Figure 22). Within each plot, species and canopy cover values were recorded. In all 64 vegetation samples, 5 m^2 in size, were used in the ordination analyses.

Modern ordination procedures are mathematically complicated and difficult if not impossible to carry out by hand. For purposes of this study, two of the Cornell University Computer Programs for Multivariate Analysis were used: DECORANA--a Fortran program for detrended correspondence analysis and reciprocal averaging, and TWINSPAN--a second Fortran program for arranging multivariate data in an ordered two-way table for classification of the individuals and attributes (Hill 1979).

Figure 23 summarizes the results of the ordination analysis of the 64 vegetation samples using DECORANA. Thirty-six species of vascular plants were encountered in the sample plots, and each species was quantitatively compared with every other species on the basis of the relative similarity and differences of their co-associates. Species that occurred together most consistently were arrayed into clusters on the ordination plot. Those sharing no common associates are separated by the greatest distance on the plot. A two dimensional ordination arranges Arabis mcdonaldiana (species number 1) closest to Arctostaphylos canescens (13) and Quercus vaccinifolia (14), two shrub species with which it is commonly associated. Horkelia tridentata (34) and Ceanothus pumilus (8) also show a relatively high level of association with Arabis on Red Mountain. Each of these plant species, on the basis of their high degree of association with Arabis, may have some utility in identifying potentially occupiable Arabis habitat.

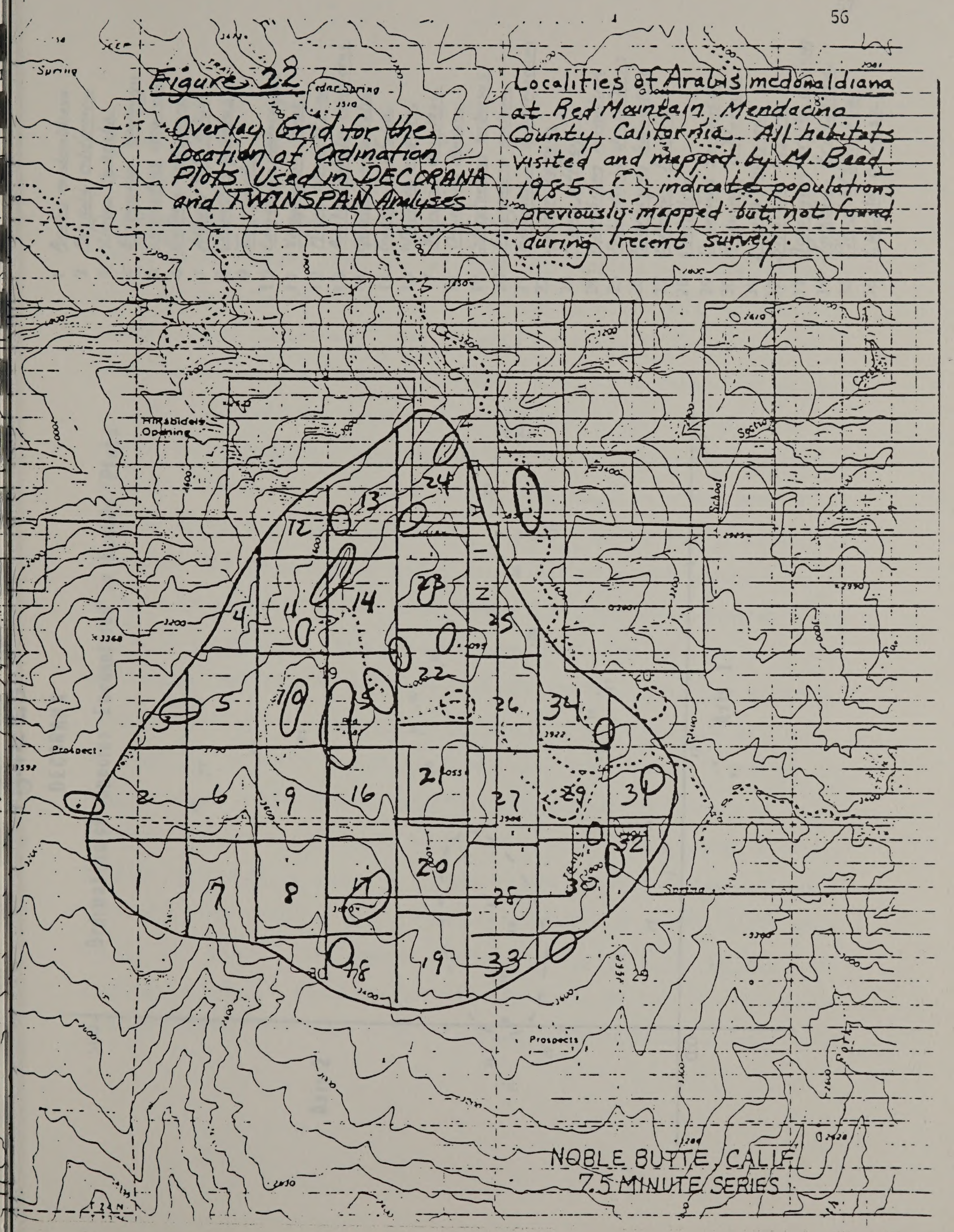
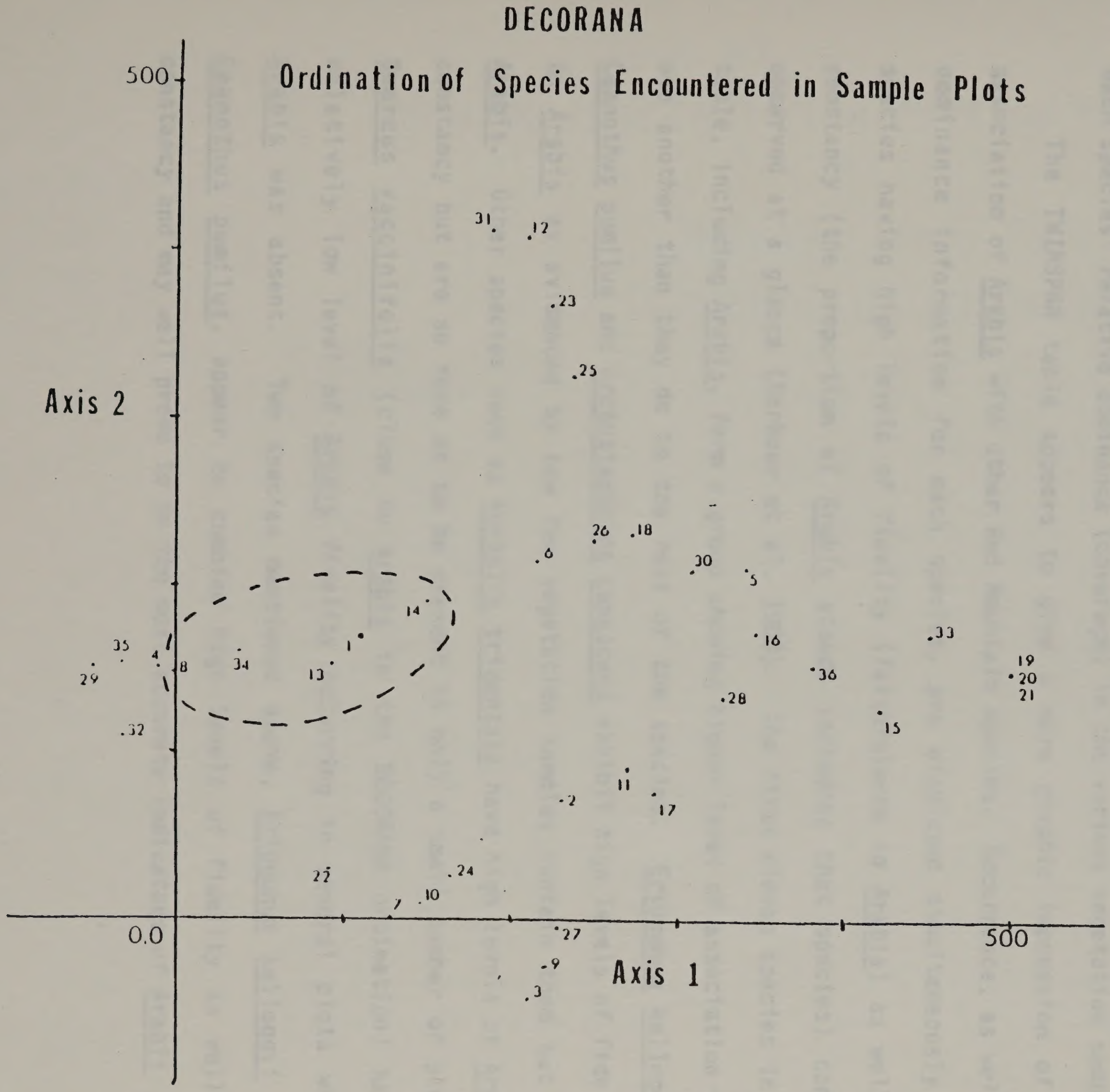


Figure 22

Overlay Grid for the Location of Ordination Plots Used in DECORANA and TWINSPAN Analyses

Localities of Arabis mcdonaldiana at Red Mountain Mendocino County, California. All habitats visited and mapped by M. Baad, 1985. ( ) indicate populations previously mapped but not found during recent survey.

Figure 23



DECORANA

Ordination of Species Encountered in Sample Plots

1	*Arabis mcdonaldiana*
2	*Polygola californica*
3	*Viola cuneata*
4	*Eriogonum kelloggii*
5	*Calocedrus decurrens*
6	*Galium ambiguum*
7	*Allium falcifolium*
8	*Ceanothus pumilus*
9	*Iris purdyi*
10	*Lomatium macrocarpum*
11	*Xerophyllum tenax*
12	*Pinus lambertiana*
13	*Arctostaphylos canescens*
14	*Quercus vaccinifolia*
15	*Garrya buxifolia*
16	*Whipplea modesta*
17	*Arenaria douglasii*
18	*Onychium densum*
19	*Streptanthus tortuosus*
20	*Eriogonum nudum*
21	*Eriodictyon californicum*
22	*Sedum laxum*
23	*Pinus jeffreyi*
24	*Epilobium minutum*
25	*Pedicularis densiflorus*
26	*Hieracium bolanderi*
27	*Lupinus lyallii*
28	*Castilleja*
29	*Cupressus sargentii*
30	*Rhamnus californica*
31	*Lilium rubescens*
32	*Sitanion hystrix*
33	*Agropyron trachycaulum*
34	*Horkelia tridentata*
35	*Pinus attenuata*
36	*Luzula comosa*

Using the same data set, the TWINSPAN analysis generates a two-way classification table as seen in Figure 24 arranging simultaneously species into groupings corresponding to high levels of association and sample plots according to high levels of similarity in species composition. The 34 species are arranged linearly along the left hand margin of the table and the sample plots horizontally across the top in order of their similarity in associates or composition respectively. The numbers in the body of the table refer to each species' relative dominance (coverage) in the various vegetation samples.

The TWINSPAN table appears to give a more graphic impression of the association of *Arabis* with other Red Mountain species. Occurrence, as well as dominance information for each species, are displayed simultaneously and species having high levels of fidelity (faithfulness to *Arabis*) as well as constancy (the proportion of *Arabis* stands including that species) can be observed at a glance (Barbour et al. 1980). The first eleven species in the table, including *Arabis*, form a group showing higher level of association with one another than they do to the rest of the species. *Eriogonum kelloggii*, *Ceanothus pumilus* and *Arctostaphylos canescens* exhibit high levels of fidelity to *Arabis* as evidenced by how few vegetation samples contain them but not *Arabis*. Other species such as *Horkelia tridentata* have high levels of *Arabis* constancy but are so rare as to be present in only a small number of plots. *Quercus vaccinifolia* (close to *Arabis* in the DECORANA ordination) has a relatively low level of *Arabis* fidelity occurring in several plots where *Arabis* was absent. Two species mentioned above, *Eriogonum kelloggii* and *Ceanothus pumilus*, appear to combine high levels of fidelity as well as constancy and may well prove to be the most accurate indicators of *Arabis*

Figure 24

TWINSPAN CLASSIFICATION of PLOTS and TAXA

Ordination Sample Plots

Taxa

```
                              556 3453362333444422334445 1 266 1454556 522 112112322111 1 355
                              12122601340789457945560134544823878826909767102919301253866634357

22 Sedum laxum                ----------1---------------------1--1-12-1------------------------  00000
29 Cupressus sargentii        ---------------------------------3-------------------------------  00000
 4 Eriogonum kelloggii        ---1--1--131-433442112313-------124---------1--------------------  00001
32 Sitanion hystrix           -------11--------------------------------------------------------  00001
35 Pinus attenuata            -------------2---------------------------------------------------  00001
 1 Arabis mcdonaldiana        121--12--112232222--111111--1-11--121111-1--------------------11-  0001
 8 Ceanothus pumilus          -1-4-3534---33554553555544555425--------12--22-3-----------------  0001
34 Horkelia tridentata        ------1--------------1-------------------------------------------  0001
 7 Allium falcifolium         --1------11------------------------------1---1--------------------  001
13 Arctostaphylos canescens   -215453------53-----------3555454456-3------------------3124-----  001
18 Onychium densum            --------1----------------------------1---1-----------------1----1  01
10 Lomatium macrocarpum       --------11----------------------------------1----------1---------  1000
23 Pinus jeffreyi             ----------1---------------------3--------32--1---1--11-21--------  1000
 3 Viola cuneata              --------------------------------------------1--------------------  100100
 9 Iris purdeyi               ---------------------------1----------------522411212121---------  100100
12 Pinus lambertiana          ----------1-1----------------1------------43-2141211--11---------  100100
26 Hieracium bolanderi        -----------------------------------------------11----------------  100100
27 Lupinus lyallii            ----------------------------------------------1----------1-------  100100
 6 Galium ambiguum            ---1-----------------------1---------------11--1--1211112-----1--  100101
11 Xerophyllum tenax          --------1-----------------------------------12---------553-------  100101
25 Pedicularis densiflorus    -----------------------------1------------1-----21-11-11---------  100101
30 Rhamnus californica        -----------------------------------------------------31----------  100101
 2 Polygala californica       ----1----------------------1----------------1---111-11----11-----  10011
16 Whipplea modesta           ------------------------------------------------22---33--51------  10011
17 Arenaria douglasii         ---------------------------------------------------1-------1----1  10100
28 Castilleja applegatei      -------------------------1-----------------------------11--1---1-  10100
15 Garrya buxifolia           1------------------1-----2-----1---------2--------1----1--3254555  101010
19 Streptanthus tortuosus     ----------------------------------------------------------------1  101011
20 Eriogonum nudum            ----------------------------------------------------------------1  101011
21 Eriodictyon californica    ----------------------------------------------------------------2  101011
33 Agropyron trachycaulum     -------------------------------------------------------------1---  101011
36 Luzula comosa              --------------------------------------------------------------1--  101011
 5 Calocedrus decurrens       -1-11--1--2----------------1--------------1-1---111-2--1-----2-2-  1011
24 Epilobium minutum          ----------------------------------------1--------------1---1-----  1011
14 Quercus vaccinifolia       5553455-1-------4------------1-------------------1434-33---1--3--  11
31 Lilium rubescens           ----1--------------------------------------1---------------------  11

                              00000000000000000000000000000000000000000011111111111111111111111
                              00000001111111111111111111111111111111111100000000000000001111111
                              00011110000000000000000000111111111111111100000111111111100111111
```

habitat. Both taxa have the additional advantages of being relatively large and easily recognizable by untrained personnel.

Summary and Conclusions

During the last three years (1984-1986), we have endeavored to study the geographical distribution, population dynamics and reproductive biology of *Arabis mcdonaldiana* within an approximately two square mile area of federal land comprising the western and southern portions of Red Mountain. This area appears to encompass approximately 80% of the known population density of this endemic taxon. The remaining populations located on private land to the east of the crest of Red Mountain were studied less intensively. Approximately coincident with the range of *Arabis*, three other taxa (*Eriogonum kelloggii*, *Sedum laxum* ssp. *eastwoodiae* and *Silene campanulata* ssp. *campanulata*) were also mapped. Of these four taxa, *Eriogonum kelloggii* appears to be the most widespread and abundant upon Red Mountain. It is also present as a small population on Little Red Mountain to the south. Although restricted in range, it appears at this point in time to have the highest ecological amplitude. In contrast, *Sedum laxum* ssp. *eastwoodiae* and *Silene campanulata* ssp. *campanulata* consist of widely scattered clusters of small numbers of individuals; total mapped populations of each species comprising no more than 250-500 individuals. *Arabis mcdonaldiana*, the major focus of this study is more widely distributed within the study area than *Sedum* or *Silene*, but less abundant than *Eriogonum*.

The population dynamics of *Arabis mcdonaldiana* were studied using a series of thirty 5 m^2 permanent sample plots placed at random within six study areas on Red Mountain. *Arabis*, a relatively long lived herbaceous perennial, was observed to maintain relatively stable population densities and coverage

values over the three years of the study although variations in both these parameters occurred within and between measured plots. One large *Arabis* population (Study Area 9) comprising from one-third to one-half of all *Arabis mcdonaldiana* individuals on Red Mountain is located at the site of a past burn and appears to be vulnerable to successional habitat degradation. Three years of population data are insufficient to conclusively document decreases in population vigor at this site, but the permanent plot data base forms an essential first step toward documentation of long term changes in the population dynamics of this critical population. Subsequent years' data will only increase the value of this information base as a management tool.

The density of *Arabis* within existing populations of the species does not appear to be limited by biotic factors. Although silique predation by rodents or other animals may periodically remove 100 percent of the reproductive output of local populations, the species' relatively long life (large individuals 27 cm in diameter may be between 25-50 years old based upon an average rate of growth of .5-1 cm/yr as obtained from permanent plot data) buffers it against short term lapses in reproductive effectiveness. In general the number of seed produced far exceeds the number of germination safe sites in the habitat, and the number of seedlings produced appears to be dependent upon some poorly understood combination of microsite interactions between climate and soil. All observations indicate that *Arabis* is restricted to Huse soils and appears to share habitat requirements with Kellogg's buckwheat (*Eriogonum kelloggii*) and Siskiyou ceanothus (*Ceanothus pumilus*). Although these indicator species do not always occur with *Arabis*, *Arabis* appears to usually be associated with them and their range of occurrence within the Red Mountain Study Area may well be a good approximation of

potential Arabis habitat. It would appear that Arabis mcdonaldiana is underoccupying its available habitat, behaving like a fugitive species with low vagility, moving from one open habitat to another with a low level of efficiency. It may be that Arabis seed are spread effectively by wind and water throughout the Red Mountain Area; the present widespread distribution of extant populations testifies to the effectiveness of dispersal over time. However in the short term, the probability of seed encountering proper conditions for germination may be so low (see results of artificial seeding experiment) that new populations are established only infrequently.

Management of Arabis mcdonaldiana within the Red Mountain Study Area

Arabis mcdonaldiana's status as an "endangered species" is due to its restricted distribution on Red Mountain and the impending threat of total habitat destruction if Red Mountain is opened to mining interests for the recovery of significant deposits of chromium and nickel ores (U.S. Fish and Wildlife Service 1984).

As a result of this study, additional populations of Arabis have been located, but these new sites do not extend the range of the species beyond the immediate vicinity of Red Mountain. Arabis populations currently occupy shallow rocky soils classified as Huse soils and the species with all likelihood is restricted to these soils because of a still to be defined habitat requirement. Although the terms Huse and Cornutt refer only to end points on a continuum of gradually changing soil quality, the distribution of Huse soils on Red Mountain can be considered for management purposes to be coincident with the occurrence of potential Arabis mcdonaldiana habitat within the study area. A new soil survey is in preparation for Red Mountain by the

Mendocino County Office of the Soil Conservation Service. Although unpublished and currently classified as preliminary by SCS, the rough soil map and soil series descriptions are included as Appendix 3 to this report. Huse and Cornutt are no longer used as soil series names in this most recent survey, and they have been replaced by Hiltabidel (roughly equivalent to Huse) and Littlered (roughly equivalent to Cornutt soil series). Red Mountain soils are variously classified as combinations of these two soil series and soils belonging to the Dann Soil Series, all soils derived from ultra basic parent material. Populations of Arabis mcdonaldiana appear to be restricted to soils classified as Hiltabidel-Dann complex and Dann-Hiltabidel-Littlered complex and are absent from Littlered clay loams (the deepest red Cornutt soils) and the Dann-Hiltabidel variant complex. Arabis appears to behave as a fugitive species, intolerant of competition, but once established, relatively long lived and persistent in habitats that were once disturbed. In habitats too unstable or rigorous for the eventual succession of shrubby vegetation such as the steep eroding talus slopes along the flanks of Red Mountain as well as the barren, exposed rock balds forming the tops of peaks and ridges, Arabis appears to form relatively stable subpopulations suffering continual losses of individuals to a shifting unstable substrate or occasional drought, but maintaining its position in the community through minimal but persistent seedling recruitment.

The species remains totally vulnerable to the large scale habitat destruction associated with mining. Road widening and maintenance connected with mining activities have the potential for severely damaging the largest extant Arabis population (Area 9--a concentration of individuals comprising approximately one-third of the total Arabis species). An existing "arterial"

road currently bisects this population. Three other Arabis populations (3, 7 and 18; see Figure 1) are also growing immediately adjacent to or in the middle of existing mining roads. Each of these last three populations occurs on private land. The remainder of the species' populations are probably more secure from accidental human disturbances associated with road maintenance, but open pit mining operations involving the Huse soils which form a reticulum throughout the Study Area will likely obliterate all existing populations.

In the absence of mining threats and road improvement activities, the four species of Red Mountain endemic plants and specifically Arabis mcdonaldiana appear to be maintaining stable populations.

A study of the reproductive biology of Arabis mcdonaldiana revealed the species to be well adapted to its habitat. The species is not restricted to a specific insect pollinator but is visited regularly by a wide range of potential pollination vectors. Two species of bumble bee, widespread throughout California, serve as its principle pollinators. In the absence of pollinators, self compatibility assures some seed set. Many populations experience some fruit predation, but these losses appear to have no significant impact on the species' ability to maintain its position in its habitat. Many more seed are produced than apparently find safe sites to germinate.

Some promise appears to exist in a program to increase the density of Arabis mcdonaldiana on Red Mountain by artificially seeding areas of Huse soils currently supporting Ceanothus pumilus and Eriogonum kelloggii. These two plants occur with Arabis with some consistency and may well serve to identify potentially and currently occupiable Arabis habitat. One must be

prepared, however, to be satisfied with a low success rate with any seeding program as normal seedling establishment rates are extremely low.

Although the majority of Arabis populations occur in zones of bedrock or unstable soils, the largest concentration of individuals occurs on a site of a past fire and a program of carefully controlled burning may introduce Arabis into currently unoccupied sites on Red Mountain.

It is strongly urged that data continue to be collected from the 30 permanent plots on Red Mountain. As argued in the body of this report, these baseline data form the nucleus of an extremely effective monitoring system allowing BLM to obtain accurate estimates of Arabis population vigor over time. It is strongly recommended that additional plots be established to incorporate the other three sensitive taxa indigenous to Red Mountain as well.

Although a three year study of any species appears to be inadequate to determine the nature of long term patterns of species recovery or decline, one inescapable conclusion can be drawn. The short term survival of Arabis mcdonaldiana is entirely dependent on the elimination of mining as a threat to the vulnerable Red Mountain habitat. Arabis, as well as the three other narrowly restricted species of Red Mountain plants, cannot be expected to coexist with an open pit mining operation, and it is strongly recommended that the U.S. Fish and Wildlife Service classify the entirety of the upper slopes of Red Mountain as critical species habitat to ensure the continued existence of Arabis mcdonaldiana. If the opportunity should arise to acquire adjacent private lands to the east, every effort should be made to bring these parcels with their associated rare plant populations under the protection of the Red Mountain Recovery Plan.

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Appendix 1

Observations from Arabis Artificial Seeding and Transplant Trials

Plot Size = 1 m²

Plot number, location and description	Visits to seed and transplant establishment plots			
	October 26, 1985	May 10, 1986	May 18, 1986	July 12, 1986
Plots 1-3 NE1/4 SE1/4, Sec. 19 T.24N, R.16W. (east-west trending test pit) Cornutt soil series.				
Plot 1 - steep south facing slope of test pit; fine red soil. Unstable slope.	Planted 100 seed Transplanted 3 Arabis in peat pots. Size: 9x7 cm 4x4 cm 3x3.5 cm	no evidence of seedlings or transplants (sheet erosion prevalent).	1 seedling*	2 seedlings*
Plot 2 - steep north facing slope of test pit;	planted 100 seed Transplanted 3 Arabis in peat pots. Size: 10x10 cm 3x3 cm 3.5x3.5 cm	no seedlings; all transplants still alive: 11x5 cm two racemes present on one. (Sugar pine seedlings have germinated).	new growth on all three transplants; no seedlings	one transplant successful to date; 6 ramets and 3 inflorescences; one eaten 2 others have 6 siliques; no seedlings
Plot 3 - gently sloping east facing slope of testpit in rocky rubble; soil yellow in color	planted 100 seed Transplanted 3 Arabis in peat pots. Size: 13x9 cm 6x4.5 cm 2.5x3 cm	no seedlings; all transplants have been grazed off but stumps beginning to resprout	no seedlings; new growth on 2 of 3 transplants	no seedlings; one transplant surviving, heavily browsed; resprouting from caudex

Plot Size = 1 m²

Plot number, location and description	Visits to seed and transplant establishment plots			
	October 26, 1985	May 10, 1986	May 18, 1986	July 12, 1986
Plots 4-6 NE1/4 SE1/4, sec. 19 T.24N, R.16W. (north-south trending test pit) Cornutt soil series				
Plot 4 - gently sloping southwest facing slope	Planted 100 seed Transplanted 2 *Arabis* in peat pots. Size: 11x13 cm 6x5 cm	no seedlings; transplants are missing apparently eaten; one survives but heavily browsed	no seedlings; one transplant still alive	no seedlings; transplant eaten back but resprouting from caudex; dia. 2 cm
Plot 5 - gently sloping northwest facing slope; pine little cover +75%	Planted 100 seed Transplanted 2 *Arabis* in peat pots. Size: 9x11 cm 3.5x4 cm	no seedlings; transplants dead (eaten)	no seedlings	no seedlings
Plot 6 - westfacing gravel heap; fine red soil	planted 100 seed Transplanted 2 *Arabis* in peat pots. Size: 7.5x9 cm 3.5x4.5 cm	no seedlings; one transplant still alive (3.5x2 cm) 2 racemes evident	no seedlings; one transplant flowering but appears to be drying up	no seedlings; transplant dead (desiccation)
Plots 7 and 8 NW1/4 SE1/4, sec. 19, T.24N., R.16W.; gently sloping east face (Huse soil series)				
Plot 7 - bare rocky slope with *Quercus vaccinifolia* and *Arctostaphylos*	planted 100 seed transplanted 2 *Arabis* in peat pots. Size: 8x10 cm 3x5.5cm	no seedlings; both transplants dead	no seedlings	no seedlings
Plot 8 - bare rocky slope	planted 100 seed transplanted 2 *Arabis* in peat pots. Size: 8x10 cm 5x6 cm	no seedlings; both transplants dead	no seedlings	no seedlings

Plot size = 1m²

Plot number, location and description	Visits to seed and transplant establishment plots			
	October 26, 1985	May 10, 1986	May 18, 1986	July 12, 1986
Plots 9 and 10 NW1/4 SE1/4, sec. 19, T.24N., R.16W. ca. 75' north of Population 9 and road (Huse Soil Series)				
Plot 9 - southfacing slope showing evidence of sheet erosion with large cobbles (1-2" dia.)	planted 100 seed transplanted 2 Arabis in peat pots. Size: 7x10 cm 4x6 cm	no seedlings; both transplants missing	no seedlings	no seedlings
Plot 10 - twenty feet west of Plot 9; adjacent to but clear of sheet erosion influence	planted 100 seed transplanted 2 Arabis in peat pots. Size: 8x9 cm 4.5x3.5 cm	no seedlings or transplants evident	no seedlings	no seedlings
Plots 11-13 SW1/4 NE1/4, sec. 19 T.24N, R.16W. approx. 30 feet west of road at top of rise (Huse soil series)				
Plot 11 - bare rocky area; gentle, east-facing slope	Planted 100 seed Transplanted 1 Arabis in peat pot Size: 2.5x3.5 cm	no seedlings or transplants evident	no seedlings	no seedlings
Plot 12 - rocky outcrop; shallow soil; shaded partially by Quercus vaccinifolia and Arctostaphylos	Planted 100 seed Transplanted 1 Arabis in peat pot. Size: 6x6.5 cm	no seedlings or transplants evident	no seedlings	no seedlings
Plot 13 - relatively flat rocky outcrop	Planted 100 seed	no seedlings	no seedlings	no seedlings

Plot size = 1m^2

Plot number, location and description	October 26, 1985	May 10, 1986	May 18, 1986	July 12, 1986
	Visits to seed and transplant establishment plots			
Plots 14-16 SW1/4 NE1/4, sec. 19 T.24N., R.16W. east and approx. 100 feet up slope from plots 11-13. (Huse soil series)				
Plot 14 - open rocky gravelly areas with deep soils	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plot 15 - open rocky slope	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plot 16 - open rocky slope	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plots 17 and 18 NE1/4 NW1/4 Sec. 29 T.24N., R.16W. on road as it nears edge of ridge; Cornutt soil series				
Plot 17 - flat open rocky area; deep red soil	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plot 18 - flat, with cobbles to 4"; partially shaded with pine needle litter (25%)	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plots 19 and 20 NW1/4 SE1/4, sec. 19 T.24N., R.16W. within Area 9 at edge of road adjacent to permanent plot 8 (Huse Soil Series				
Plot 19 - open area; gravelly soil	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plot 20 - open area; gravelly soil	Planted 100 seed	no seedlings	no seedlings	no seedlings

Plot size = 1m²

Plot number, location and description	Visits to seed and transplant establishment plots			
	October 26, 1985	May 10, 1986	May 18, 1986	July 12, 1986
Plots 21-23 SE1/4 NE1/4, sec. 19 T.24N., R.16W. open rocky area on northeast-facing slope; approx. 150 feet west of road (Huse Soil Series)				
Plot 21 -	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plot 22 -	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plot 23 -	Planted 100 seed	no seedlings	no seedlings	no seedlings
Plots 24-28 NW1/4 NE1/4, sec. 19, T.24N., R.16W. on edges of soil embankment left from soil test pit; just north of spur road running east from main road				
Plot 24	100 seed	no seedlings	no seedlings	no seedlings
Plot 25	100 seed	no seedlings	no seedlings	no seedlings
Plot 26	100 seed	no seedlings	no seedlings	no seedlings
Plot 27	100 seed	no seedlings	no seedlings	no seedlings
Plot 28	100 seed	no seedlings	no seedlings	no seedlings
Plots 29 and 30 NW1/4 NE1/4, sec. 19, T.24N., R.16W. on lower east-facing flank of ridge occupied by population 15.				
Plot 29	100 seed	no seedlings	no seedlings	no seedlings
Plot 30	100 seed	no seedlings	no seedlings	no seedlings

Appendix 2

Vascular Plants Encountered on Red Mountain

List compiled from personal collections and those of Knight and Knight (1971)
(Baad's collections deposited at California State University, Sacramento)
Nomenclature based on Munz and Keck (1970)

Adiantum pedatum var. *aleuticum*	Western maiden-hair
Agoseris heterophylla	Annual agoseris
Allium amplectens	Narrow-leaved onion
Allium bolanderi	Bolander's onion
Allium falcifolium	Scythe-leaved onion
Alnus rhombifolia	White alder
Amelanchier pallida	Service-berry
Amsinckia intermedia	Common fiddleneck
Aquilegia eximia	Columbine
Arabis mcdonaldiana	McDonald's rock-cress
Arbutus menziesii	Madrone
Arceuthobium campylopodum	Western dwarf mistletoe
Arctostaphylos canescens	Hoary manzanita
Arctostaphylos stanfordiana	Stanford's manzanita
Arenaria douglasii	Douglas' sandwort
Brodiaea laxa	Ithurial's spear
Calamagrostis inexpansa	Blue joint
Calocedrus decurrens	Incense cedar
Calochortus tolmiei	Tolmie's star tulip
Calycadenia truncata	Rosin weed
Carex concinnoides	Northwestern sedge
Carex mendocinensis	Mendocino sedge
Carex phyllomanica	Coastal stellate sedge
Castilleja applegatei	Wavy-leaved paintbrush
Ceanothus integerrimus	Deer brush
Ceanothus pumilus	Siskiyou ceanothus
Cirsium coulteri	Coulter thistle
Clarkia amoena	Farewell to spring
Clarkia purpurea ssp. *viminea*	Godetia

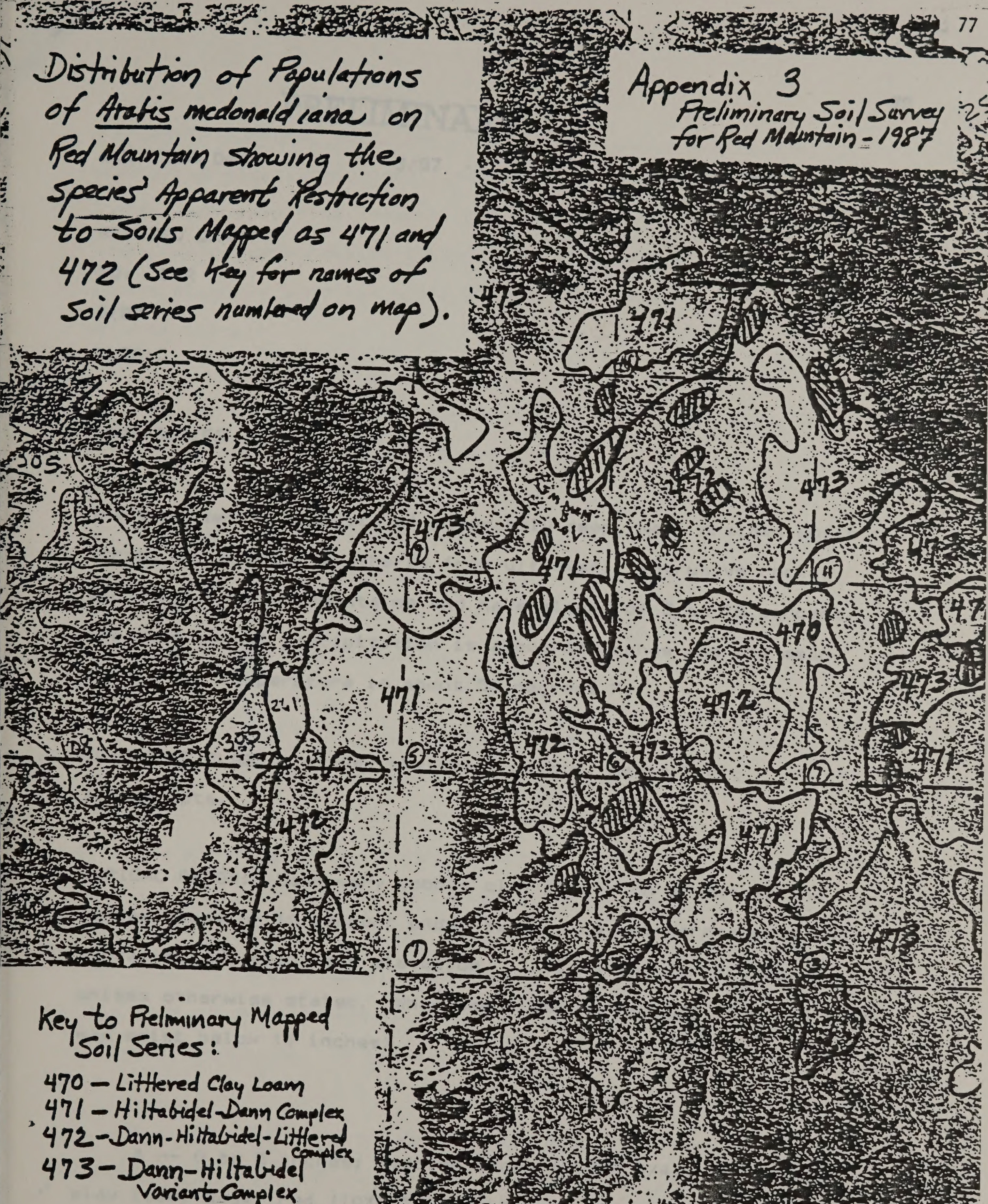
Convolvulus nyctagineus	Oregon morning-glory
Cryptantha milobakeri	Milo Baker's cryptantha
Cryptantha torreyana	Torrey's cryptantha
Cypripedium californicum	California lady's slipper
Dentaria californica var. *sinuata*	California toothwort
Dentaria pachystigma	Stout-beaked toothwort
Elymus glaucus	Western rye-grass
Epilobium minutum	Minute willow-herb
Eriodictyon californicum	California yerba santa
Erigeron foliosus var. *hartwegii*	Leafy daisy
Erigeron inornatus var. *viscidulus*	California rayless daisy
Eriogonum kelloggii	Kellogg's eriogonum
Eriogonum latifolium ssp. *nudum*	Naked-stemmed eriogonum
Eriogonum vimineum	Wicker eriogonum
Erythronium californicum	California fawn lily
Eschscholzia californica var. *crocea*	Interior california poppy
Festuca grayi	Gray's fescue
Festuca occidentalis	Western fescue
Galium ambiguum ssp. *siskiyouense*	Yolla bolly bedstraw
Garrya buxifolia	Dwarf silk-tassel
Gaultheria shallon	Salal
Gentiana setigera	Elegant gentian
Gilia capitata ssp. *staminea*	Gilia
Habenaria elegans	Elegant piperia
Habenaria sparsiflora	Sparsely flowered bog orchid
Hemizonia tracyi	Tracy's tarweed
Heuchera micrantha	Alum root
Hieracium bolanderi	Bolander's hawkweed
Hieracium greenei	Greene's hawkweed
Horkelia tridentata ssp. *flavescens*	Three-toothed horkelia
Iris purdyi	Purdy's iris
Juncus effusus var. *pacificus*	Bog rush
Juncus ensifolius	Three-stamened rush
Juncus xiphioides	Iris-leaved rush
Lilium rubescens	Lilac Lily

Linanthus bicolor	Bicolored linanthus
Linanthus bolanderi	Bolander's linanthus
Linum clevelandii var. *petrophilum*	Cleveland's dwarf flax
Linum micranthum	Small-flowered dwarf flax
Lithocarpus densiflora	Tan-bark oak
Lithophragma affine	Woodland star
Lomatium engelmannii	Engelmann's lomatium
Lomatium macrocarpum	Large-fruited lomatium
Lomatium tomentosum	Wooly lomatium
Lomatium tracyi	Tracy's lomatium
Lotus denticulatus	
Lotus humistratus	
Luina hypoleuca	Little leaf luina
Lupinus lyallii	Lyall's lupine
Luzula comosa	Common wood-rush
Madia minima	Small madia
Melica geyeri	Geyer's onion-grass
Microseris douglasii	Douglas's microseris
Mimulus kelloggii	Kellogg's monkey-flower
Narthecium californicum	California bog-asphodel
Navarretia intertexta	Needle-leaved navarretia
Nemacladus capillaris	Common nemacladus
Nemophila menziesii	Baby blue-eyes
Nemophila parviflora	Small-flowered primrose
Oenothera graciliflora	Slender-flowered primrose
Orobanche fasciculata	Clustered broomrape
Parnassia palustris var. *californica*	California grass-of-parnassus
Pedicularis densiflora	Indian warrior
Phacelia corymbosa	Serpentine phacelia
Phacelia egena	Kaweah phacelia
Pinus jeffreyi	Jeffrey pine
Pinus lambertiana	Sugar pine
Pinus ponderosa	Ponderosa pine
Plagiobothrys nothofulvus	Rusty popcorn flower
Polygala californica	California milkwort

Polygonum spergulariaeforme	Spurry knotweed
Pseudotsuga menziesii	Douglas fir
Quercus chrysolepis	Canyon live oak
Quercus kelloggii	Black oak
Quercus vaccinifolia	Huckleberry oak
Rhammus californica	California coffeeberry
Rhododendron occidentalis	Western azalea
Rigiopappus leptocladus	Rigiopappus
Schoenolirion album	White-flowered Schoenolirion
Scirpus criniger	Fringed bulrush
Sedum laxum ssp. *eastwoodiae*	Stonecrop
Sedum spathulifolium	Pacific stonecrop
Sedum stenopetalum ssp. *radiatum*	Star-fruited stonecrop
Selaginella wallacei	Wallace's selaginella
Silene campanulata ssp. *campanulata*	Campanulate campion
Sitanion hystrix	Bottle-brush squirrel-tail
Stachys rigida ssp. *rigida*	Rigid hedge nettle
Synthyris reniformis var. *cordata*	Snowqueen
Trifolium dichotomum	Branched Indian clover
Trifolium fucatum	Sour clover
Trifolium eriocephalum	Woolly-headed clover
Umbellularia californica	Bay
Vaccinium parvifolium	Red huckleberry
Vicia americana var. *truncata*	American vetch
Viola cuneata	Wedge-leaved violet
Whipplea modesta	Yerba de selva
Xerophyllum tenax	Western turkey-beard
Zigadenus micranthus	Small-flowered zigadene

Appendix 3
Preliminary Soil Survey for Red Mountain - 1987

Distribution of Populations of *Arabis mcdonaldiana* on Red Mountain showing the Species' Apparent Restriction to Soils Mapped as 471 and 472 (See Key for names of Soil series numbered on map).



Key to Preliminary Mapped Soil Series:

470 — Littered Clay Loam
471 — Hiltabidel-Dann Complex
472 — Dann-Hiltabidel-Littered complex
473 — Dann-Hiltabidel Variant Complex

PRELIMINARY

LOCATION DANN 3/87 . CA

REVISED DRAFT

RD: CAR

3/87

MLRA:5

DANN SERIES

The Dann series consists of moderately deep, well drained soils formed in material weathered from ultramafic intrusive rocks. Dann soils are on mountains and have slopes of 5 to 75 percent. The mean annual precipitation is about 65 inches and the mean annual air temperature is about 55 degrees F.

TAXONOMIC CLASS: clayey-skeletal, oxidic, mesic Typic Xerochrepts.

TYPICAL PEDON: Dann very cobbly clay loam - on a west facing convex slope of 10 percent under sugar pine, ponderosa pine and manzanita, at 4030 feet elevation. (Colors are for dry soil unless otherwise stated. When described on May 22, 1980 the soil was moist below 10 inches).

A -- 0 to 5 inches; reddish brown (2.5YR 4/4) very cobbly clay loam, dusky red (10~~Y~~R 3/3) moist; strong very fine and fine

granular structure; soft, very friable, slightly sticky and slightly plastic; many very fine and fine, and common medium roots; many very fine interstitial pores; 5 percent pebbles (2-75mm), 30 percent cobbles (7.5-25cm) and 10 percent stones (25-
✓ ~~28~~ 40cm); slightly acid (pH 6.4); abrupt wavy boundary. (3 to
✓ ~~6~~ 5 inches thick)

Bw1 -- 5 to 21 inches; strong brown (7.5YR 5/6) extremely stony clay loam, dark brown (7.5YR 4/4) moist; weak very fine granular structure; soft, very friable, sticky and slightly plastic; many very fine and fine and common medium roots; many fine interstitial pores; 5 percent pebbles (2-75mm), 15 percent cobbles (7.5-25cm) and 50 percent stones (25-6~~7~~5cm); neutral (pH 6.8); clear irregular boundary. (10 to 21 inches thick)

Bw2 -- 21 to 31 inches; strong brown (7.5YR 5/6) extremely stony clay loam; dark brown (7.5YR 4/4) moist; weak fine subangular blocky structure; soft, very friable, sticky and slightly plastic; common fine and medium roots; common very fine interstitial pores; 10 percent greenish gray (5GY 6/1) saprolite with black (N 2/0) and strong brown (7.5YR 5/8) stains along fractures; 5 percent pebbles (2-75mm), 15 percent cobbles (7.5-25cm) and 50 percent stones (25-6~~7~~5cm); neutral (pH 7.0); abrupt irregular boundary. (7 to 14 inches thick)

R -- 31 to 60 inches; variegated reddish yellow (7.5YR 7/8) and greenish gray (5GY 6/1) hard, fractured, slightly weathered

peridotite; many black (N 2/0) stains within fractures that are 1 to 2mm and 3 to 10cm apart.

TYPE LOCATION: Mendocino County, California; from U.S. Hwy 101 frontage road south of Reynolds, turn on Red Mountain access road and head about 4.5 miles to Cat Track road, head 5.5 miles to quarry, 10 feet west of road; 2150 feet south and 1800 feet west of the northeast corner of sec. 19, T.24N., R.16W.; Leggett quadrangle.

RANGE IN CHARACTERISTICS: Depth to a lithic contact and thickness of the solum ranges from 20 to 40 inches. The mean annual soil temperature ranges from 53 to 57 degrees F. The soil between a depth of 10 and 35 inches or to a lithic contact, whichever is shallower, is moist in all parts from November 1 to June 1 and is dry in all parts from July 15 to October 1 in most years. Base saturation (sum) ranges from 50 to 75 percent throughout the profile. 25 to 40 percent of the soil surface is covered with cobbles and 5 to 15 percent is covered with stones. The particle-size control section averages 35 to 40 percent clay. Reaction is slightly acid or neutral throughout the profile.

The A horizon is 2.5YR 4/4, 5/4 or 5YR 5/4. moist color is 10R 3/3, 3/4; 2.5YR 3/4 or 3/6. Clay content ranges from 27 to 35 percent. Gravel content is 2 to 10 percent, cobble comtent is 25 to 35 percent, and stone content is 5 to 15 percent. Total coarse fragment content is 35 to 60 percent.

The Bw horizon is 7.5YR 4/6, 5/4, 5/6, 6/6 or 5YR 5/4. Moist color is 7.5YR 4/4, 4/6; 5YR 4/4, 4/6; 2.5Y 3/4 or 3/6. It is very stony clay loam, extremely stony clay loam or very stony clay with 35 to 50 percent clay. Total coarse fragment content is 35 to 70 percent. Gravel content is 2 to 10 percent, cobble content is 15 to 45 percent, and stone content is 25 to 60 percent.

COMPETING SERIES: There are no other series in the same family.

GEOGRAPHIC SETTING: Dann soils are on mountains. Slopes are 5 to 75 percent. Elevations are 2000 to 4100 feet. Dann soils formed in material weathered from ultramafic intrusive rocks. The climate is subhumid with hot dry summers and cool moist winters. Mean annual precipitation is 60 to 70 inches with occasional snowfall. Mean January temperature is about 45 degrees F.; mean July temperature is about 66 degrees F.; and the mean annual temperature is about 55 degrees F. The frost-free season is 150 to 250 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Casabonne, Hiltabidel (T), Hollowtree (T), Holohan (T), and Littlered soils. Casabonne, Hollowtree and Holohan soils formed from sandstone. They occur on the mountains surrounding the ultramafic rock intrusion on which Dann, Hiltabidel and Litlered soils formed. Hiltabidel and Holohan soils are greater than 40 inches deep to a

lithic coontact. Casabonne soils are greater than 40 inches deep to a paralithic contact. Littlered soils are less than 20 inches deep to a lithic contact. Hollowtree soils have argillic horizons and have mixed mineralogy.

DRAINAGE AND PERMEABILITY: Well drained, surface runoff under bare soil conditions is medium through very rapid; moderately slow permeability.

USE AND VEGETATION: This soil is used for wildlife and watershed. Vegetation consists of sugar pine, ponderosa pine, incense cedar, Jeffrey pine, manzanita, bracken fern, buckwheat, silene spp. and stonecrop. Chemical characteristics, including a low calcium to magnesium ratio restrict plant growth and influence species composition.

DISTRIBUTION AND EXTENT: Mendocino County, California, Red Mountain area. This series is not extensive.

SERIES PROPOSED: Mendocino County, Western Part, California, 1981. Source of the name is Dann Creek.

REMARKS: Diagnostic horizons and features recognized in this soil:

1. Ochric epipedon -- 0 to 5 inches (A), ranges from 3 to 6 inches thick

2. Cambic horizon -- 5 to 31 inches (Bw1, Bw2), ranges from 17 to 35 inches thick. Higher clay content than overlying horizon but no evidence of illuviation. Clay content by field estimate: Bw1 = 38 percent, Bw2 = 38 percent. Base saturation is 84 percent (ammonium acetate)

3. Lithic contact -- hard peridotite at 31 inches. Range in depth to bedrock is 20 to 40 inches. Rock does not slake in water.

4. Particle-size class -- clayey-skeletal. Particle-size control section, 10 to 31 inches, contains 70 percent rock fragments and 38 percent clay (field estimate)

5. Soil moisture and temperature -- assumed to be xeric and mesic based on temperature and moisture studies in the area under similar vegetation and similar elevations

6. Mineralogy -- oxidic. Dithionite-citrate extractable iron: Bw1 = 30.4 percent; Bw2 = 19.0 percent

7. Lincoln Lab samples 817284, 817285, 821748-821750

National Cooperative Soil Survey
U.S.A.

11\30\81

PRELIMINARY

LOCATION HILTABIDEL 12/86 CA

Tentative Series
IRD:CAR
12/86
MLRA: 5

HILTABIDEL SERIES

The Hiltabidel series consists of shallow, well drained soils formed in material weathered from ultrabasic intrusive rocks. Hiltabidel soils are on mountains and have slopes of 5 to 75 percent. The mean annual precipitation is about 65 inches and the mean annual air temperature is about 55 degrees F.

TAXONOMIC CLASS: loamy-skeletal, oxidic, nonacid, mesic Lithic Xerorthents.

TYPICAL PEDON: Hiltabidel very stony clay loam - on a southwest facing slope of 58 percent under knobcone pine and manzanita at 3,820 feet elevation. (Colors are for dry soil unless otherwise stated. When described May 22, 1980, the soil was moist throughout.)

0--1/2 inch to 0; litter of knobcone pine and manzanita leaves and twigs.

A1--0 to 13 inches; reddish brown (5YR 4/4) very stony clay loam, dark reddish brown (2.5YR 3/4) moist; moderate very fine and fine granular structure; soft, very friable, slightly sticky and slightly plastic; many very fine and fine and common medium roots; many very fine and fine interstitial pores; 30 percent cobbles (8-25cm), 20 percent stones (25-60cm); neutral (pH 6.7); gradual irregular boundary.

A2--13 to 17 inches; reddish brown (5YR 4/4) extremely stony clay loam, dark reddish brown (2.5YR 3/4) moist; moderate very fine granular structure; soft, very friable, slightly sticky and slightly plastic; common medium and fine and very few fine roots; many very fine and fine interstitial pores; 20 percent cobbles (8-25cm), 55 percent stones (25-60cm); neutral (pH 6.7); abrupt irregular boundary.

R--17 inches; variegated reddish yellow (7.5YR 7/8) and gray (5Y 5/1, 6/1) hard, fractured peridotite; many black (N 2/0) magnetite and manganese stains within fractures that are 1 to 2mm wide and 3 to 10cm apart, in random orientation.

TYPE LOACTION: Mendocino County California; about 1,600 feet south and 3,200 feet west of the norhteast corner sec. 19, T.24N., R.16W., MDBM, Noble Butte quadrangle.

RANGE IN CHARACTERISTICS: Depth to lithic contact is 10 to 20 inches. The mean annual soil temperature ranges from 53 to 57 degrees F. The soil between a depth of 8 inches and bedrock is moist in all parts from November 1 to June 1 and is dry in all parts from July 15 through October 1 in most years. There are 20 to 50 percent cobbles and 10 to 40 percent stones on the soil surface. Base saturation (HACH) ranges from 70 to 95 percent throughout. Reaction is slightly acid or neutral throughout.

The A horizon is 2.5YR 3/4, 4/4; 5YR 4/3 or 4/4. Moist color is 10R 3/4; 2.5YR 3/4 or 4/4. It is very stony or extremely stony clay loam. Clay content ranges from 27 to 35 percent. Cobble content ranges from 15 to 45 percent and stone content ranges from 20 to 55 percent. Total coarse fragment content ranges from 35 to 80 percent.

COMPETING SERIES: There are no series in the same family. The Dann and Littlered series are closely related. The Dann series is 20 to 40 inches deep to a lithic contact. Littlered soils are very deep.

GEOGRAPHIC SETTING: Hiltabidel soils are on mountains. Slopes are 5 to 75 percent. Elevations are 2,000 to 4,100 feet. The soils formed in material weatherd from ultrabasic intrusive rocks. The climate is subhumid with hot dry summers and cool moist winters. The mean annual precipitation ranges from 60 to 70 inches with occasional snowfall. Mean January temperature is about 45 degrees F., mean July temperature is about 66 degrees F., and the mean annual temperature is about 55 degrees F. The frost-free season is 150 to 250 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the closely related Dann and Littlered soils and the Casabonne, Hollowtree and Holohan series. Casabonne, Hollowtree and Holohan soils formed from sandstone that surrounds the ultrabasic rocks from which Hiltabidel soils were formed. Casabonne soils are fine-loamy. Hollowtree and Holohan soils have mixed mineralogy and are greater than 20 inches deep.

DRAINAGE AND PERMEABILITY: Well drained, surface runoff under bare soil conditions is medium through very rapid; moderate permeability.

USE AND VEGETATION: This soil is used as wildlife habitat and as watershed. Vegetation consists of knobcone pine, incense cedar, manzanita and ceanothus. Chemical

characteristics including a low calcium to magnesium ratio, restrict plant growth and influence species composition.

DISTRIBUTION AND EXTENT: Northern coastal California. The series is not extensive.

SERIES PROPOSED; Mendocino County, California, Western part, 1986. Soil name is from Hiltabidel opening.

REMARKS: Diagnostic horizons and features recognized:

1. Ochric epipedon - 0 to 17 inches (A1, A2)
2. Mineralogy - Oxidic 10.3 percent dithonite-citrate extractable Fe clay percentage = 33
3. Reaction class - nonacid. Reaction ranges from 6.1 to 7.3 throughout.
4. Many areas of Hiltabidel soils were mapped as Huse series in the Wildland Soils and Associated Vegetation of the Mendocino County California by the State Cooperative Soil Vegetation Survey 1947-1950.

National Cooperative Soil Survey
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PRELIMINARY

LOCATION LITTLERED 12/86 CA

Tentative Series
IRD:CAR
12/86
MLRA:5

LITTLERED SERIES

The Littlered series consists of very deep, well drained soils that formed in material weathered from ultrabasic intrusive rocks. Littlered soils are on mountains and have slopes of 2 to 30 percent. The mean annual precipitation is about 65 inches and the mean annual air temperature is about 55 degrees F.

TAXONOMIC CLASS: Clayey, ferritic, mesic Xeric Haplohumults.

TYPICAL PEDON: Littlered clay loam - on a northwest facing slope of 10 percent under ponderosa and sugar pine at 2,720 feet elevation. (Colors are for dry soil unless otherwise stated. When described on May 21, 1980, the soil was moist below 10 inches.)

0--1/2 inch to 0; dark red (2.5YR 3/6) clay loam, dusky red (10R 3/4) moist; strong very fine granular structure; soft, friable, slightly sticky and slightly plastic; many very fine and fine and common medium roots; many very fine interstitial pores; 5 percent cobbles (8-25cm) and 2 percent stones (25-35cm) neutral (pH 7.0); abrupt irregular boundary. (5 to 15 inches thick)

A -- 0 to 10 inches; dark red (2.5YR 3/6) clay loam, dusky red (10R 3/4) moist; strong very fine granular structure; soft, friable, slightly sticky and slightly plastic; many very fine and fine and common medium roots; many very fine interstitial pores; 5 percent cobbles (8-25cm) and 2 percent stones (25-35cm) neutral (pH 7.0); abrupt irregular boundary. (5 to 15 inches thick)

Bt--10 to 26 inches; yellowish red (5YR 5/6) clay loam, dark reddish brown (5YR 3/4) moist; weak fine granular structure; soft, friable, sticky and slightly plastic; common medium and few fine roots; many very fine interstitial pores; few thin clay films on peds and in pores; 5 percent cobbles (8-25cm) and 2 percent stones (25-35cm); mildly alkaline (pH 7.5); abrupt wavy boundary. (13 to 20 inches thick)

C--26 to 65 inches; strong brown (7.5YR 5/8) loam, strong brown (7.5YR 4/6) moist with many black (N2/0) manganese stains on peds and in pores; weak, fine subangular blocky structure; soft, friable, sticky and slightly

plastic; few medium roots; many very fine interstitial pores; 5 percent cobbles (8-25cm) and 2 percent stones (25-35cm); mildly alkaline (pH 7.5). (30 to 50 inches deep)

TYPE LOCATION: Mendocino County California; about 1,500 feet south and 600 feet west of the northeast corner of sec. 6, T.23N., R.16W., MDBM, Leggett quadrangle.

RANGE IN CHARACTERISTICS: Depth to bedrock is greater than 60 inches. Organic carbon content in the upper meter of soil averages 0.8 to 1.0 percent. The mean annual soil temperature ranges from 53 to 57 degrees F. The soil between the depths of 6 and 10 inches is moist in all parts from November 1 to June 1 and is dry in all parts from July 15 to October 1 in most years. Cobble content ranges from 0 to 10 percent and stone content ranges from 0 to 5 percent throughout the profile.

The A horizon is 2.5YR 3/4, 3/6, 4/4; 5YR 4/3 or 4/4. Moist color is 2.5YR 3/4, 4/4; 10R 3/4 or 4/4. Clay content ranges from 27 to 35 percent. Reaction is slightly acid or neutral.

The Bt horizon is 5YR 5/4, 5/6 or 7.5YR 5/6. Moist color is 5YR 3/3, 3/4 or 7.5YR 4/4. It is clay loam or clay with a clay content of 35 to 45 percent. Base saturation ranges from 5 to 25 percent. Reaction is neutral or mildly alkaline.

The C horizon is 5YR 5/8; 7.5YR 5/6 or 5/8. Moist color is 5YR 4/6; 7.5YR 4/4 or 4/6. It is loam or clay loam with a clay content of 20 to 40 percent. Base saturation ranges from 10 to 25 percent. Reaction is neutral or mildly alkaline.

COMPETING SERIES: There are no series in the same family but the Aiken, Dann (T) and Sites series are closely related. Aiken and Sites series have oxidic mineralogy. The Dann series is clayey-skeletal.

GEOGRAPHIC SETTING: The Littlered soils occur on mountains. Slopes are 2 to 30 percent. Elevations are 2,000 to 4,100 feet. The soil formed in material weathered from ultrabasic intrusive rocks. The climate is subhumid with hot dry summers and cool moist winters. The mean annual precipitation ranges from 60 to 70 inches with occasional snowfall. Mean January temperature is about 45 degrees F.; mean July temperature is about 66 degrees F., and the mean annual temperature is about 55 degrees F. The frost-free season is 150 to 250 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Casabonne, Dann, Hollowtree, Holohan, and Hiltabidel series. Casabonne, Hollowtree and Holohan soils formed from

sandstone that surrounds the ultrabasic rocks from which Dann, Littlred and Hiltabidel soils were formed. Casabonne soils are fine-loamy. Holohan and Hollowtree soils are loamy-skeletal. Dann soils are moderately deep and Hiltabidel soils are shallow to lithic contact.

DRAINAGE AND PERMEABILITY: Well drained; surface runoff under bare soil conditions is slow through rapid, moderate permeability.

USE AND VEGETATION: This soil is used as wildlife habitat and as watershed. Vegetation consists of Jeffrey pine, ponderosa pine, incense cedar, tanoak, ceanothus and manzanita. Chemical characteristics, including an extremely low calcium to magnesium ratio restrict plant growth and influence species compostions.

DISTRIBUTION AND EXTENT: Northern coastal California. The series is not extensive.

SERIES PROPOSED: Mendocino County, California, Western part 1986. Soil name is from Little Red Mountain.

REMARKS: Diagnostic horizons and features recognized:

1. Ochric epipedon - 0 to 10 inches (A)
   Organic carbon content A = 2.7 percent (assumed greater than 0.9 percent in upper 6 inches of the argillic horizon.
2. Argillic horizon - 10 to 26 inches (Bt) clay content by field estimate A = 28 percent, Bt = 35 percent C = 30 percent
3. Base saturation (HACH kit) A = 20 percent, Bt = 18 percent, C = 20 percent
4. Mineralogy - Ferritic - 33 percent dithionite - citrate extractable Fe. Moderate amount of goethite, small amount of hematite NSSL #817283
5. Many areas of Littlered soils were mapped as Cornutt series in the Wildland Soils and Associated Vegetation of Mendocino County California, by the State Cooperative Soil Vegetation Survey 1947-1950.

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